CMHC
Canada Mortgage
and Housing Corporation

SCHL
Societe canadienne
d'hypotheques et de logement

Tumbler Ridge Planning Framework for Energy-Conservation Planners

Research Report

August 1983

Canada

38

Canada Mortgage and Housing Corporation, the Federal Government's housing agency, is responsible for administering the National Housing Act.

This legislation is designed to aid in the improvement of housing and living conditions in Canada. As a result, the Corporation has interests in all aspects of housing and urban growth and development.

Under Part V of this Act, the Government of Canada provides funds to CMHC to conduct research into the social, economic and technical aspects of housing and related fields, and to undertake the publishing and distribution of the results of this research. CMHC therefore has a statutory responsibility to make widely available, information which may be useful in the improvement of housing and living conditions.

This publication is one of the many items of information published by CMHC with the assistance of federal funds.

TUMBLER RIDGE

PLANNING FRAMEWORK FOR

ENERGY-CONSERVATION PLANNERS

Prepared for
The Technical Research Division
Policy Development and Research Sector
of
Canada Mortgage and Housing Corporation

by

Planning Collaborative Inc.
122 Sherbourne Street
Toronto, Ontario
M5A 2R4

Principal Consultant: Thomas E. Martin
CMHC Project Manager: G. Hiscox, Vancouver

This project was funded by CMHC, but the views expressed are the personal views of the author, and no responsibility for them should be attributed to the Corporation.

TABLE OF CONTENTS

	Page
1. Community Energy Planning	1
2. The Tumbler Ridge Energy Studies	3
2.1 Background	3
2.2 Environmental Setting	6
2.3 Study 1: District Heating	8
• Implications	10
2.4 Study 2: Energy-Efficient Housing	13
• Implications	19
2.5 Study 3: Energy-Efficient Subdivisions	22
• Implications	23
2.6 Study 4: Alternative Financing Mechanisms	25
3. Study Relationships	26
4. Conceptual Framework	32
4.1 Conclusions	37
5. Bibliography	40

ENERGY PLANNING FOR NEW COMMUNITY DEVELOPMENT: LESSONS FROM TUMBLER RIDGE

1. Community Energy Planning

A new community requires several kinds of energy over its lifetime. Firstly, energy is required to construct the community: fuel and temporary power to operate vehicles, equipment, machines, etc. Secondly, the community requires energy in order to function:

- electricity, the essential energy, for motors, lights, equipment
- thermal energy for space heating and domestic hot water
- fuel to operate the vehicles required by residents and businesses.

Resource exploitation, the very reason for the existence of a resource community, may also consume prodigious amounts of energy. The activities of extraction, processing, and transportation may consume several times again as much energy as the entire community itself: again, requiring electricity for motors, processing, etc., fuels for vehicles and equipment, thermal energy for space heating, hot water, industrial processing, and so on.

Energy planning for new community development, like any planning process, is concerned with the efficient allocation of resources, subject to constraints on those resources. Usually energy planning is thought of in terms of dealing with the community's energy supply. However, the complementary aspect, energy conservation, is equally important, since a community generally has two ways to save on energy costs: 1) by lowering the cost of the energy consumed (affecting energy supply), and 2) by demanding or consuming less energy (through conservation).

As a process, energy planning is usually iterative; that is, involving several cycles in which the supply and demand variables are adjusted or fine-tuned to develop more efficient solutions. This is illustrated in Chapter 3, Study Relationships. As a further complication, planning operates in a dynamic context of outside factors, most of which are not under the control of the community development team. In energy planning, these uncontrollable factors include the weather, the environment, available energy supply options, energy price fluctuations, interest rates, and the political decision-making framework. It is also strongly affected by variables wholely or partially controlled by the team. These include programmatic elements of the community such as its population and housing mix; process elements such as the pace of growth and its projected lifespan; financial, institutional, and other constraints.

Like transportation planning, which deals with a service to be utilized rather than an end product, energy planning deals with a means to an end. It must be subordinated to, and integrated with, the larger and more complex goals of community development. This means for example, that a less than optimal energy plan may have to be accepted in return for achieving more effectively, the social, physical and financial goals of the community. This principle will continue to hold true, although changing real

world circumstances may lead planners to value energy inputs more highly than they have in the past.

Energy planning has recently taken on added importance. One of the obvious reasons for this is cost: the several-fold price increases occurring over the last decade, coupled with wild fluctuations in energy costs, inflation, and interest rates, just in the last two to three years. Communities, buildings, and infrastructure are built to last and be amortized over much longer periods of time, usually a minimum of 20 to 30 years. Therefore, one of the major concerns in energy planning is how to minimize the costs of energy-related investments and energy costs in the face of these external fluctuations. These concerns are accentuated in Canadian resource communities whose relative isolation not only increases energy costs, but also often reduces the energy supply options available.

The second major impetus for energy planning is that certain forms of energy are now seen to be scarce and non-renewable. Irrespective of the fact that energy costs have moderated temporarily, in the long run, energy conservation is a public good which extends the life of present sources and reduces dependence on imported supplies. Once again, this is accentuated in remote communities, because imported energy sources not only have to be brought into the country, but also transported across Canada to remote locations. The costs of building an infrastructure to bring much closer regional energy sources such as hydro-electric power or natural gas to a remote location such as Tumbler Ridge can still be formidable.

2. The Tumbler Ridge Energy Studies

2.1 Background

Both the supply and conservation aspects of community energy planning were investigated in four innovative studies undertaken by private consultants to determine the opportunities for energy-saving measures at Tumbler Ridge, the new community being built to accommodate the labour force for the North East Coal development in British Columbia.

The studies were managed by Canada Mortgage and Housing Corporation, and the British Columbia Ministry of Energy, Mines, and Petroleum Resources, with funds provided by Energy, Mines, and Resources Canada. They were to determine the feasibility of:

1) A District Heating System for the Town (CoGeneration Associates Limited)

2) Cost-Effective Energy-Efficient New Housing (Saskatchewan Research Council)

3) Energy-Efficient Subdivisions (Planning Collaborative Inc.)

4) Financing Alternatives for Energy-Efficient Housing (Edwin, Reid & Associates).

The Town development process started so quickly that planning and engineering design were well advanced by the time the studies were commissioned, and thus, they lacked some of the impact they might have had if the results has been introduced earlier in the community development process. Although the studies were undertaken more or less at the same time, with discussions among the authors, the full range of potential relationships among them was not explored until this report, which takes a retrospective look at the entire energy planning process. Changes in energy prices and interest rates have also affected the results of the studies, although not their underlying rationales.

The studies were done in late 1981 and early 1982, a time of historically high interest rates (18 to 20%), as well as high energy prices. At the time, there were strong concerns about the affordability of energy-efficient housing (in fact, any housing) at Tumbler Ridge. Since then, interest rates have moderated greatly, and the rate in increase in energy prices has slowed as well, with some energy costs remaining nearly constant, or even declining.

Study 1 is concerned with the aspect of community energy supply. Normally community planners would not be able to affect this aspect because most major energy sources originate from outside the community. In Tumbler Ridge's case, the presence of a local fuel source, coal, created the opportunity for influencing how the Town would be heated.

By contrast, the aspect of energy conservation usually can be controlled by community planners, since it is affected by the manner in which the community physical infrastructure of roads, services, and buildings is planned, financed, and utilized. These aspects are examined in Studies 2, 3, and 4.

These two aspects can work against each other. An expensive energy supply encourages energy conservation measures since each energy unit (expressed in Giga Joules (GJ*)) is valuable, thereby allowing more capital dollars to be invested in order to save it. A cheap energy supply encourages consumption and lessens the economic viability of energy conservation measures, since each GJ saved is less valuable.

Supply and conservation also have different institutional characteristics:

- Conservation measures are almost infinitely divisible. In a community of 2,400 homes, 1, 2, 100, or 2,400 homes can be made energy-efficient; the same holds for measures such as narrower lots. Within a house or building, measures such as insulation are similarly divisible. They can be undertaken in whole or in part, by individuals, small and large builders. Although the sums expended for energy conservation may be large in total, the costs for any individual installation can be small. Any amount up to this grand total can be spent within the community, depending on circumstances.

  In principle, an individual should be willing to spend on energy conservation measures up to the expected value of the energy savings (although hopefully much less than this). The length of time required to pay off these costs in energy savings is termed the "payback period". In the case of measures borne by businesses or the public sector, this period should be less than the expected life of the measure itself, or the life of the community. Tumbler Ridge is fortunate in apparently having a longer anticipated lifespan than most resource communities, which in turn permits capital works to be amortized over longer terms, and allows a wide range of measures (with longer payback periods) to be considered.

  Homeowners are likely to take a shorter range view of energy conservation measures, preferring to have them paid off within the time they expect to occupy the house. At a maximum, this will be 10 years or less, and preferably under 5 years for most homeowners.

- Energy supply measures are usually large-scale and indivisible (or "lumpy"). The possible exception to this lies in solar or photo-voltaic installations. Hydro and gas transmission lines, constructed over 50 to 80 km, as at Tumbler Ridge, or district heating plants, are multi-

---

* GJ = Giga Joule, a measure of energy
1 GJ = 1 billion joules
= 9,478 BTU (British Thermal Units)
= 277.7 kWh

million dollar investments. They must be either done in their entirety or not at all. Therefore, when they are undertaken, it is usually by governments or quasi-public corporations. These investments require a guaranteed market, usually in the form of a monopoly.

Because infrastructure costs are high and fuel costs relatively low, the larger the load (in terms of the number of units supplied or the demand per unit), the more cost-effective the installation will be. This results because the capital costs can be spread out over a larger number of consumers.

2.2 Environmental Setting

A description of the Tumbler Ridge environmental setting is important for understanding the context for the energy studies.

Tumbler Ridge was chosen as the townsite for the North East Coal development by the British Columbia Government in 1977. A comprehensive Conceptual Plan was prepared to provide a social, physical, financial, and organizational framework for a community with an ultimate population of 10,500. The initial stages of development to 1990 envisage a population of approximately 6,200, housed in 2,400 units. All of the energy studies were based on these 1990 figures.

The townsite is located at 55°8' North Latitude and 121°0' West Longitude, some 660 km north of Vancouver, and 515 km west of Edmonton. The nearest existing communities are Chetwynd and Dawson Creek, each about 88 km to the north (Figure 1). The relative isolation of Tumbler Ridge results in construction cost premiums of 15 to 30% more than these communities, because of the distances over which labour, materials, and fuels must be imported, and because the workforce must be housed in camps.

Tumbler Ridge lies east of the Rocky Mountains on the boundary between the Alberta Plateau and Rocky Mountain foothills, and consists of several gravel terraces facing west above the Murray River and Flatbed Creek. The ridge itself, from which the Town draws its name, rises 300 m to the east (Figure 2). To the west, the site overlooks the valleys of the Murray River, Wolverine River, abd Bullmoose Creek which drain the foothills and mountains containing the various coal-bearing formations upon which the town will depend. The gravel terraces are bounded by a steep scarp up to 80 m high. separating them from the floodplains of the Murray River and Flatbed Creek.

Although the townsite has a commanding setting, the buildable land area is limited, necessitating a compact community form, so as not to waste this resource, and allow some flexibility for future development. Also, the site is constrained on all sides, putting definite limits on the physical extent of the Town. The favourable setting for the Town was used to advantage in developing the planning principles described in Study 3.

Climatically, Tumbler Ridge is affected by two main influences: continental weather systems with outbursts of cold arctic air masses, coupled with the periodic intrusion of Pacific frontal systems. This provides the region with long cold winters and warm summers with moderate precipitation. The coldest period of the year is from mid-January to mid-February. Average temperatures are -20 to -18°C, and range as low as -45 to -40°C. Average temperatures in summer are 10 to 16°C, with hot periods as high as 29 to 32°C. Heating degree days for the year are 6,152 (Celsius), or 4,838 for the heating season from November to April. These values are typical of the cold middle latitudes of Canada, and correspond very closely to those of Saskatoon, for example.

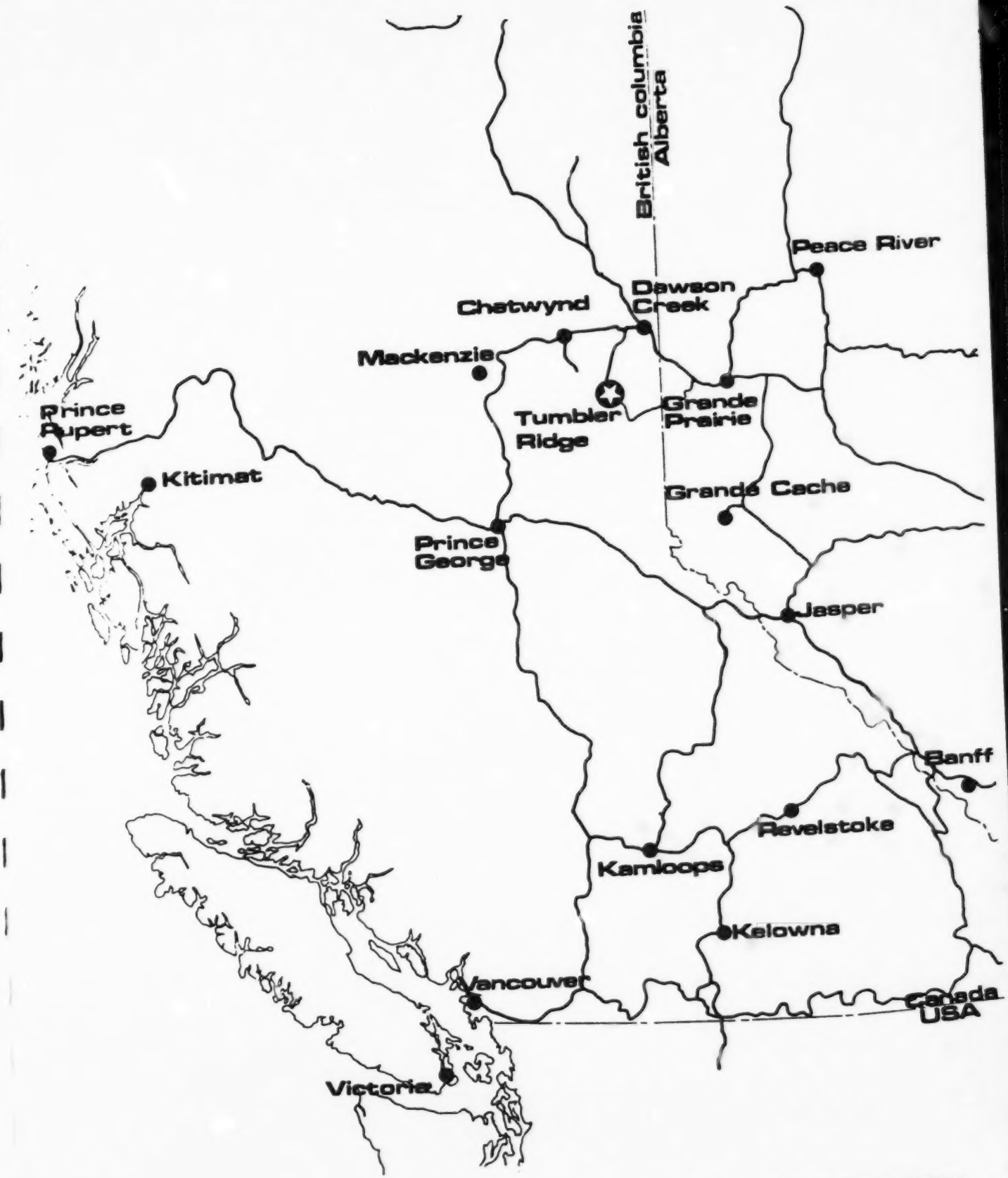

British Columbia
Alberta
Peace River
Dawson Creek
Chetwynd
Mackenzie
Tumbler Ridge
Grande Prairie
Prince Rupert
Kitimat
Grande Cache
Prince George
Jasper
Banff
Revelstoke
Kamloops
Kelowna
Vancouver
Canada
USA
Victoria
REGIONAL LOCATION
0 km 100 100
0 mi 50 100
North

Figure 1

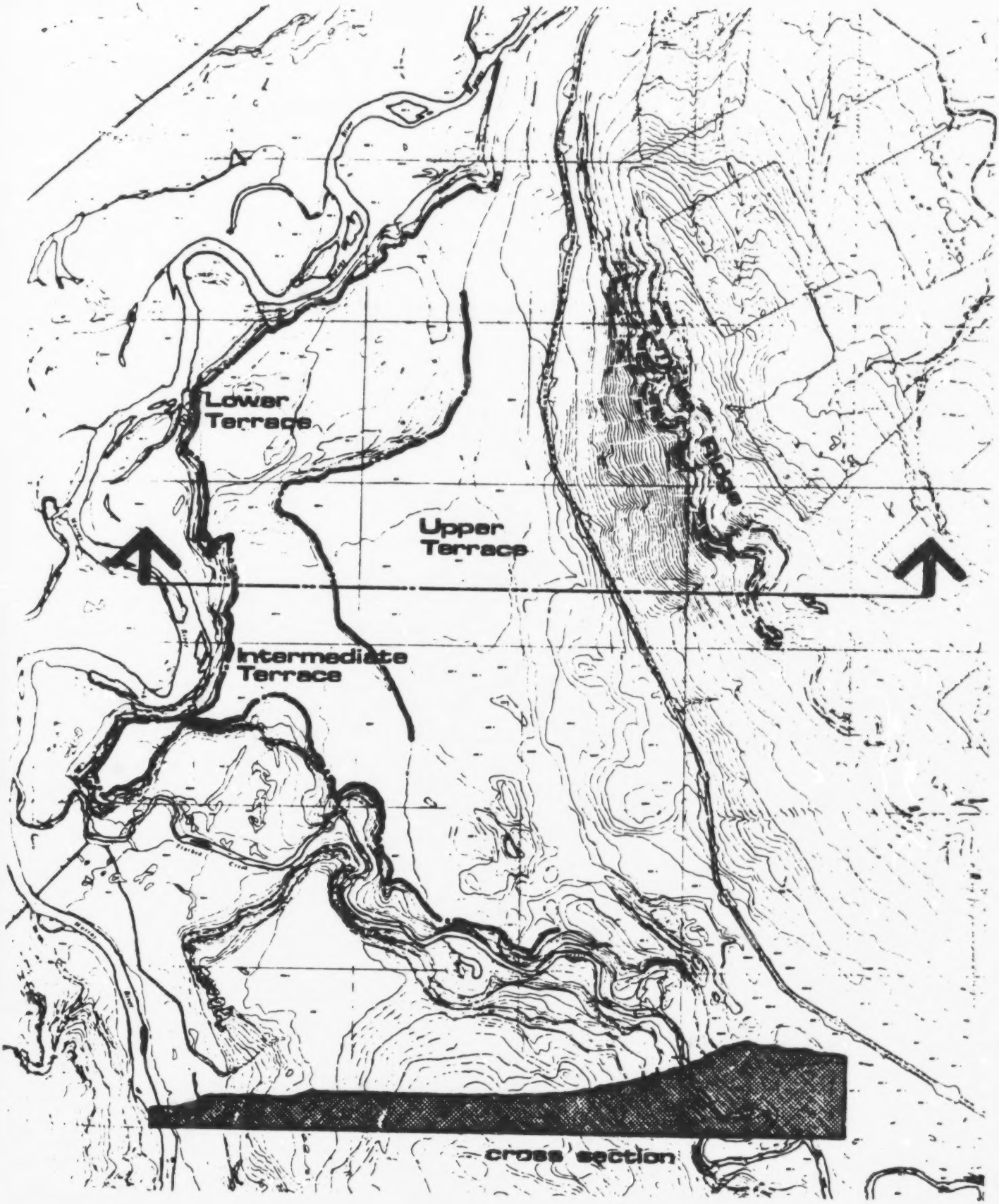


Figure 2

RELIEF

Wind is also a constant factor on the townsite year-round, coming from the south and south-west at an average speed of 18 km/h.

At the high latitudes of Tumbler Ridge, winter sun angles are low and cast very long shadows. For example, at noon on December 21st, the sun's altitude is only 11°33', barely above the 10° altitude felt to constitute " useful" solar radiation for passive solar heating purposes. However the sun's altitude rises rapidly with each succeeding month, giving useful solar radiation after mid-January or before mid-November.

From this description, it can be seen that Tumbler Ridge has aspects which are both typical and atypical of Canadian resource communities. Some of the typical aspects include the relatively harsh (but not unusually cold) climate, the exceptional natural setting of the townsite, the community's partial isolation, and its dependence on energy-intensive resource extraction. Some of the atypical aspects include:

- a diverse (rather than narrow) resource base, which includes coal, forestry, and natural gas. The sale of coal is committed to Japanese interests for up to 25 years, with proven reserves of much longer duration. The Town has an expected lifespan much longer than that of most narrowly-based communities.

- The community is isolated, but other communities are also nearby, within 80 km. It is feasible to connect the Town to the hydro-electric power grid, and possibly to a regional natural gas distribution network. Therefore, several competing and relatively low cost energy sources are available, an unusual condition for a resource community.

- The Town has good transportation connections by air, road, and rail to the rest of the province. Large numbers of private vehicles can be expected on the townsite. In turn, fuel economies were feasible from reducing the length of the community's internal road network.

- The natural resource at Tumbler Ridge is also a fuel, usable with relatively little processing (as compared, for example, with oil which must be refined). This created the potential for district heating at Tumbler Ridge, making use of this cheap, locally available fuel.

2.3 Study 1: District Heating

The "District Heating" Study for Tumbler Ridge was really a succession of reports of increasing detail and refinement, initially undertaken to determine the most effective means of providing heat to the Town. The consulting engineering firm of CoGeneration Associates Limited was engaged by CMHC to undertake the first of these reports; a comprehensive energy analysis of the townsite, and various integrated methods for supplying energy to it.

The consultant investigated six energy supply options:

a) natural gas (space heating and domestic hot water) for the entire Town

b) natural gas supplied to high density buildings, and electricity (space heating and domestic hot water) to low density buildings

c) natural gas to supply a central heating plant to heat high density buildings (near the Town Centre) and electricity providing heat to low density buildings

d) as c), with municipal solid waste also used as a fuel in the central heating plant

e) district heating with co-generation of electricity, with coal-fired boilers

f) coal-fired district heating without co-generation of electricity.

The study process included the following steps:

1) Review of the planning schedule for the Town, and estimates of energy use (both for space heating and electricity).

   Figure 3 represents an updated version of the space heating energy estimate, assuming a "Measures" level of construction for all buildings. (this level of construction is described in Study 2).

2) Estimates of energy use by end use and customer category; estimates of hourly peak demand (important in sizing central district heating plant).

3) Description of energy supply options

4) Calculation of the supply system capacity required for each scheme.

   (This calculation is based on the peak and total energy demands, and is factored up to design energy levels depending on the particular system. In the case of electrical heating, assumed to be 100% efficient, no factoring is necessary; with natural gas forced air furnaces, the energy levels are factored up to reflect furnace conversion inefficiencies; with district heating, the factoring reflects heat losses in the distribution piping)

5) Costing of each supply scheme.

Figure 3

CALCULATION OF COMMUNITY HEATING DEMAND
("Measures" Level of Construction)

Residential

Unit Type	Number of Units	GJ/unit/year	Total (000 GJ)
Large Detached	507	103	52.2
Small Detached	510	85	43.4
Large Semi-Detached	65	91	5.9
Small Semi-Detached	70	64	4.5
Row Houses	110	36	4.0
Apartments	740	17	12.6
Pre-Built	388	113	43.8
TOTALS	2,390		166.4
		Domestic Hot Water	53.3
		Total Residential Demand	219.7 (000 GJ)

Commercial & Institutional

	Space Heating	47.0
	Domestic Hot Water	5.0
	Total Commercial & Institutional Demand	52.0 (000 GJ)

Community

Total Community Demand	271.7 (000 GJ/year)

6) Preparation of a financial analysis to rank all schemes.

7) Recommendation of a preferred energy supply option for the Town.

The preferred option was a district heating system burning mostly coal in a central plant. This plant would supply heat to the Town through an underground low temperature hot water distribution system, and co-generate electricity in addition. However, the co-generation alternative had a higher capital cost and greater technological complexity than district heating without co-generation, CAL's second-ranked option. For these reasons, district heating without co-generation, with a capital cost of approximately $10,000,000, was recommended by CAL for further study.

The firm of INTEG - Intercontinental Engineering Limited of Vancouver was then commissioned by the District of Tumbler Ridge to undertake a preliminary engineering design and financial analysis of a district heating system for the Town. INTEG provided a design concept based on co-generation, using a high pressure steam plant, with an estimated system cost of $21,420,000. Subsequently, a number of changes were made in the design, which reduced the cost of the complete system to $14,707,000 (still with co-generation).

In a third report, CAL was further able to reduce the total estimated system cost to $12,600,000, having received a turnkey submission for the hot water heating plant (without co-generation) with a firm price $2,100,000 below engineering estimates. Operating costs were also reduced by $200,000 annually because full time operating engineers were not required to be in attendance, as with the steam plant option.

The design of this final (CAL) district heating system was based on circulating hot water at 120^{o}C delivered to the users, who would install equipment suitable for removing energy from the system for their heating and domestic hot water requirements. The return water to the heating plant would be at 55^{o}C. The hot water distribution system would be factory-insulated steel pipe buried directly in the soil at a depth of about 0.5 m.

The central district heating plant per se (based on the turnkey submission) proposed heating of an organic fluid (oil) in coil tube boilers operating at atmospheric pressure. This oil is heated to 300^{o}C and circulated through heat exchangers to heat the water for distribution to users. The particular advantage of this system over high pressure steam or hot water plants was that operating engineers were not required. However, such oil systems operate at lower conversion efficiencies than steam or hot water plants and are not readily converted to co-generation (which requires high pressure steam to operate turbines).

Within individual buildings, space heat can be supplied through air (fan coil units and ductwork) or hydronic systems using the district heating water directly in hot water radiation baseboards, a significantly cheaper prospect. Heat for domestic hot water is supplied through an external heat exchanger around the potable hot water tank.

In its final report, CAL concluded that a new town such as Tumbler Ridge was an ideal site for demonstrating an effective technology to deliver thermal energy. Favourable conditions in a "green field" setting include:

- location of the central heating plant can be centred in the community to reduce piping costs and thermal losses in the distribution system
- new dwelling units can be adapted to use hot water heating without retrofit costs
- pipes for the distribution system can be laid when streets are excavated for the installation of other utilities
- fuel for the system was inexpensive and locally available (using residual coal). Municipal garbage could also be incinerated in the plant, saving on the cost of a separate incineration plant (necessary with other energy supply options).

Implications of District Heating

- Necessity of a Local Fuel Source

District Heating is a local (community-based) system with a central heating plant, an expensive (but short) distribution network, and locally available fuels such as coal, garbage, wood by-products, etc. The thermal energy distributed may also be the surplus heat generated by an industrial process. Local fuels appear to be an important prerequisite, because the costs of district heating fueled by more expensive natural gas or oil are greater than a conventional natural gas piped distribution system and individual furnaces in each building.

- Sensitivity to Capital Costs and Interest Rates

By far the largest percentage of the cost of delivered DH energy lies in the amortization of its capital costs, split roughly 35:53:12 at Tumbler Ridge between the central plant, the distribution network, and incidental costs, respectively. (Figure 4). Therefore, the viability of a DH system is highly sensitive to capital costs and interest rates (Figure 5), and must be justified financially on the specifics of a particular application at one point in time. For example, Figure 5 shows that District Heating is very competitive at Tumbler Ridge under low capital costs and 12% interest rate assumptions ($8.81/GJ), but becomes less competitive as capital costs and/or interest rates rise. As a local system with a limited radius of service from a central plant, DH cannot be built as a branch of a regional system already in place and paid for (as might be the case with other energy sources such as natural gas or electricity).

The initial cost estimates of the District Heating study were favourable, but subsequently varied between $21.4 and $12.6 million as the system engineering design was refined. These variations had a corresponding major effect in delivered energy prices, which are the basis for comparison with other energy supply options. Naturally, such shifts made it difficult for the community development team to evaluate the various supply options consistently. The credibility of the financial analysis is im-

Figure 4

DISTRICT HEATING CAPITAL COSTS

	1982 $	
Heating Plant	$4,430,000	) 35%
Distribution System	6,672,000	) 53%
Instrumentation	541,000	)
Engineering	820,000	) 12%
Testing	125,000	)
TOTAL	$12,588,000	

Source: CoGeneration Associates Limited (1982)

Figure 5

DISTRICT HEATING: SENSITIVITY OF UNIT ENERGY COSTS TO CAPITAL COST ESTIMATES AND INTEREST RATES

INTEG (Initial) Capital Cost Estimate: $21,420,000

Interest Rate	Total Annual Amortization Cost	Amortization Cost Represented $/GJ*	Total Delivered Energy Cost $/GJ
12% (25 years)	$2,707,209	$9.99	$12.94
15% "	3,292,248	12.12	$15.07
18% "	3,900,400	14.36	17.31

CAL (Final) Capital Cost Estimate: $12,588,000

12% (25 years)	$1,590,959	$5.86	$8.81 •
15% "	1,934,772	7.12	10.07
18% "	2,292,170	8.44	11.39

* Based on a community annual thermal energy demand of 271,700 GJ (Figure 3)

portant when a relatively unfamiliar technology is being compared with more familiar options such as natural gas and electricity.

• Lumpiness of the Capital Investment

Another characteristic of District Heating is that many operating costs of the system are fixed (labour, amortization, etc.), with the result that major variations in the costs of fuel (provided it is cheap to begin with) or energy demand, will not affect the total delivered costs of energy. If demand falls off sharply for some reason such as widespread conservation, the DH fixed costs would still have to be paid. This defines a threshold energy cost for each household.

Since household energy costs cannot be reduced below this minimum, the incentive for energy-efficient construction is reduced with DH. Similarly, there is less incentive for ongoing energy conservation, because the household's energy costs do not rise proportionately with increasing consumption, as fuel represents such a small percentage of the total. However, differential pricing related to use could be employed as a policy to encourage energy conservation, even though delivered costs in the system do not vary significantly.

By comparison, other energy systems such as grid electricity and natural gas have regional or province-wide rates which distribute the capital costs of major generating installations and trunk distribution networks over large areas and hundreds of thousands of customers. The capital costs of their local networks are lower than for DH, with small diameter pipes or wires, no insulation, low transmission losses. The costs of adding a local distribution area on to a large system are quite small relative to the other costs of the system. While large industrial users often receive preferential tariffs, residential rates are usually set so that user energy costs vary directly with consumption. Provided it is economical to begin with, DH could operate at an advantage here for the household, since its costs do not increase as quickly as demand rises. These cost differentials among supply options have a direct effect on which level of energy conservation will be optimal in a community. This is discussed in some detail in Chapter 4: Study Relationships.

• Compulsory Participation

Because the capital costs of the local DH network are high, it needs all the users it can get, within its radius of service. Households or businesses cannot be selectively connected, or given other choices such as electric baseboards or natural gas furnaces.

Compulsory participation may have political implications. It would certainly be more difficult to install a DH system after the Town was well under construction, because it would involve replacing building heating systems with new systems, or installing temporary heating. Either option has costs which would be resisted by cunsumers. Ideally the DH distribu-

tion system should be in place like sewers, water, and electicity, before much building construction is started, requiring only the house service connections in order to be fully operational. The negative aspects of comulsory participation would be reduced in this case because DH would be treated like any other essential utility. However, consumers may still have to be convinced that DH is clearly their cheapest space heating system.

DH transmission losses are also relatively high, and therefore, it may have a limited effective range of distribution. This should encourage the development of a compact community, or may restrict the use of the system to a high-density Town Centre Area which can be reached with short distribution lines, provided the central plant can be operated economically.

- Institutional Constraints

Institutional considerations are mentioned in several of the reports on District Heating. Since DH is a local system, a local utility is required to operate it. Investor-owned local utilities are common in the United States, but Canadian utilities tend to be public or quasi-public in nature, often covering wide regional service areas. Therefore, it was proposed that the Town of Tumbler Ridge raise the necessary funds, supervise the installation of the DH system, and later operate it as a Section within its Department of Works.

This would be an added responsibility for a Town administration faced with the complexities of developing a new community, as well as a substantial debt load for conventional services and infrastructure. Lacking a base of technological experience in District Heating, the Town would probably require technical assistance and risk guarantees from senior levels of government in order to implement a DH system. An alternative management option would be to form another entity to undertake the project, possibly with Town representation, but separately funded, so as not to increase the Town's debt load.

2.4 Energy-Efficient Housing

The Saskatchewan Research Council undertook this study with several objectives in mind:

- To review the various aspects of Tumbler Ridge and determine their probable influence on energy-efficient housing construction. This included a study of energy use options and their costs, prevailing building techniques and construction factors, material availability, supply problems, state of preparedness of the local building industry, etc.

- To evolve a range of conceptual house designs, covering various levels of energy-efficiency, and to analyse the cost-effectiveness of each.

- To propose methods and techniques for transferring the technology of energy-efficient construction to the builders and sub-trades involved in the project - during both the design and construction phases. The proposed methods and techniques were to take into account the probable levels of energy-efficiency, builders' familiarity with the techniques, the mix of large and small builders, the inspection facilities available, local expertise, and the potential for creating expertise.

- To propose a program for measuring and monitoring the performance of the residential units. This involved consideration of the aims of the monitoring phase, and of the local resources available for the work.

Four different levels of construction were considered: 1975 Standard construction, "Measures", "Retrofit Ready", and "Super Energy Efficient". Approximate levels of insulation and infiltration were developed for each, and the space heating requirements were calculated for representative designs of detached units, semi-detached, row, apartment, and pre-built (mobile home) units for each level of energy-efficiency. This calculation used a simple equation developed by the Saskatchewan Research Council. The incremental cost of the energy-efficient components was estimated on the basis of information supplied by builders in nearby Dawson Creek. The various figures were analysed to determine the effect of energy conservation measures on the monthly payments of homeowners.

The details of the various levels of energy-efficient construction were as follows:

1. 1975 Standard (included as a baseline of the incremental analysis, based on a platform-built bungalow with concrete basement) (Figure 6)

   - Ceiling insulation RSI 3.5
   - Wall insulation RSI 2.1
   - No foundation wall insulation or slab insulation
   - 2-mil polyethylene vapour barrier
   - Standard hip roof trusses
   - No air management or passive solar design.

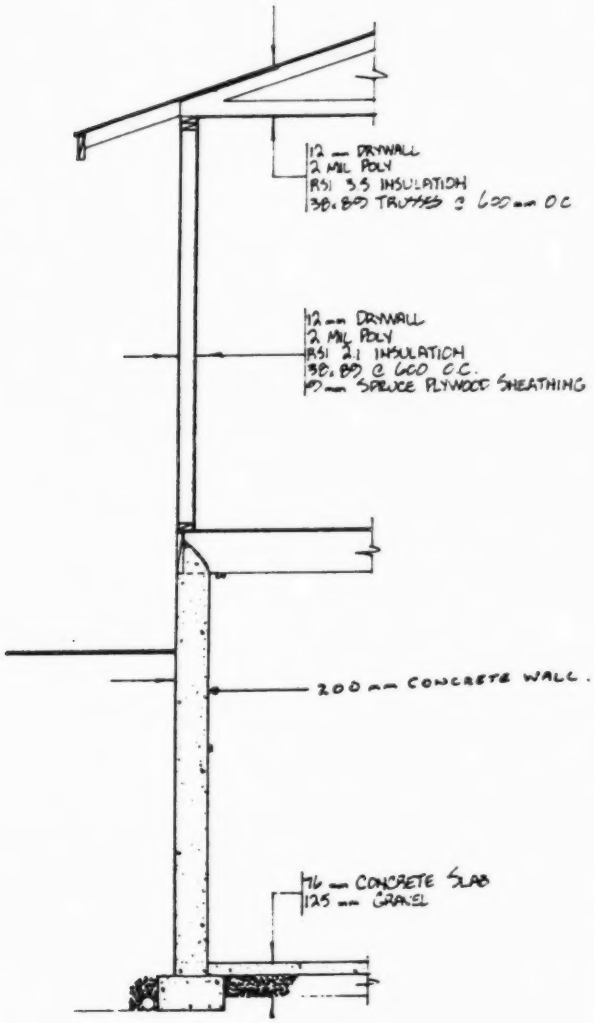


Figure 6 1975 Standard

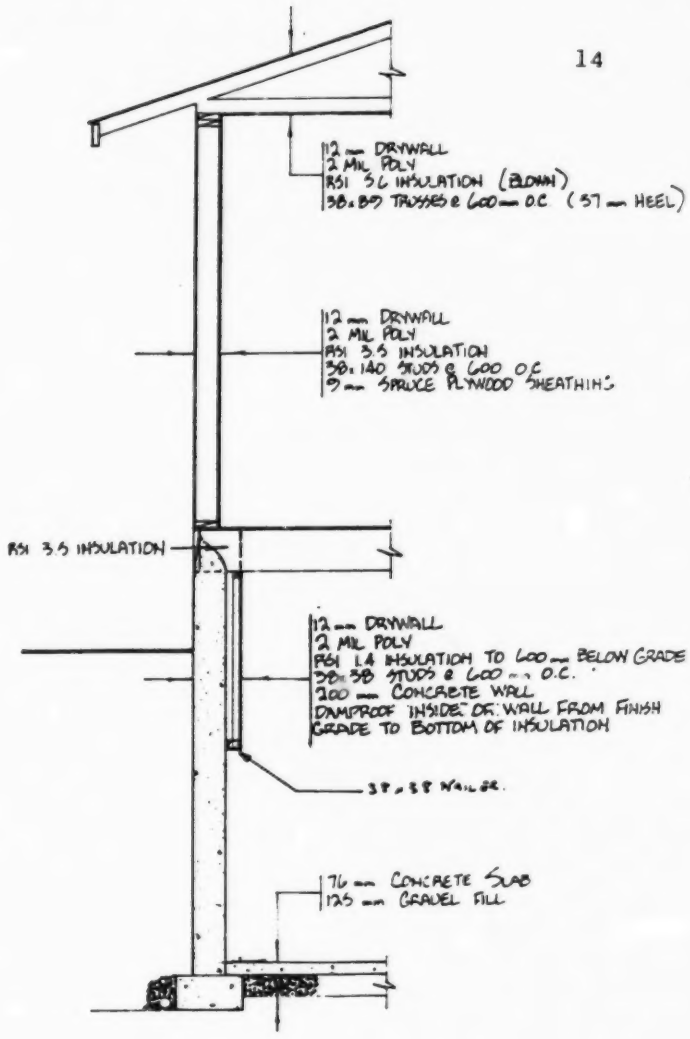

12 — DRYWALL
2 MIL POLY
RSI 5.6 INSULATION (BLOWN)
38.89 TRUSSES @ 600 — OC (57 — HEEL)
12 — DRYWALL
2 MIL POLY
RSI 3.5 INSULATION
38.140 STUDS @ 600 OC
9 — SPRUCE PLYWOOD SHEATHING
RSI 3.5 INSULATION
12 — DRYWALL
2 MIL POLY
RSI 1.4 INSULATION TO 600 — BELOW GRADE
38.38 STUDS @ 600 — O.C.
200 — CONCRETE WALL
DAMPROOF INSIDE OF WALL FROM FINISH
GRADE TO BOTTOM OF INSULATION
38.38 WALL
76 — CONCRETE SLAB
125 — GRAVEL FILL

Figure 7 Measures 1

2. Measures conforms to, and is named after, the 1978 NRC publication "Measures for Energy Conservation in New Buildings", shortly to be adopted as standard minimum construction in British Columbia (Figure 7).

   - Ceiling insulation RSI 5.6
   - Wall insulation RSI 3.5
   - Foundation insulation RSI 1.4 for the top 1.2 m
   - No slab insulation
   - Roof trusses with 57 mm heel
   - Wall construction 38 x 140 studs @ 600 mm o.c.
   - Foundation stud frame 38 x 38 @ 600 mm o.c.
   - 2-mil polyethylene vapour barrier with sealing around doors and windows
   - No air management, but some passive solar design.

   Two other variants were also proposed:

   - Measures 2, with RSI 3.4 insulation in the walls, using a combination of exterior rigid insulation and RSI 2.1 batts in a 38 x 89

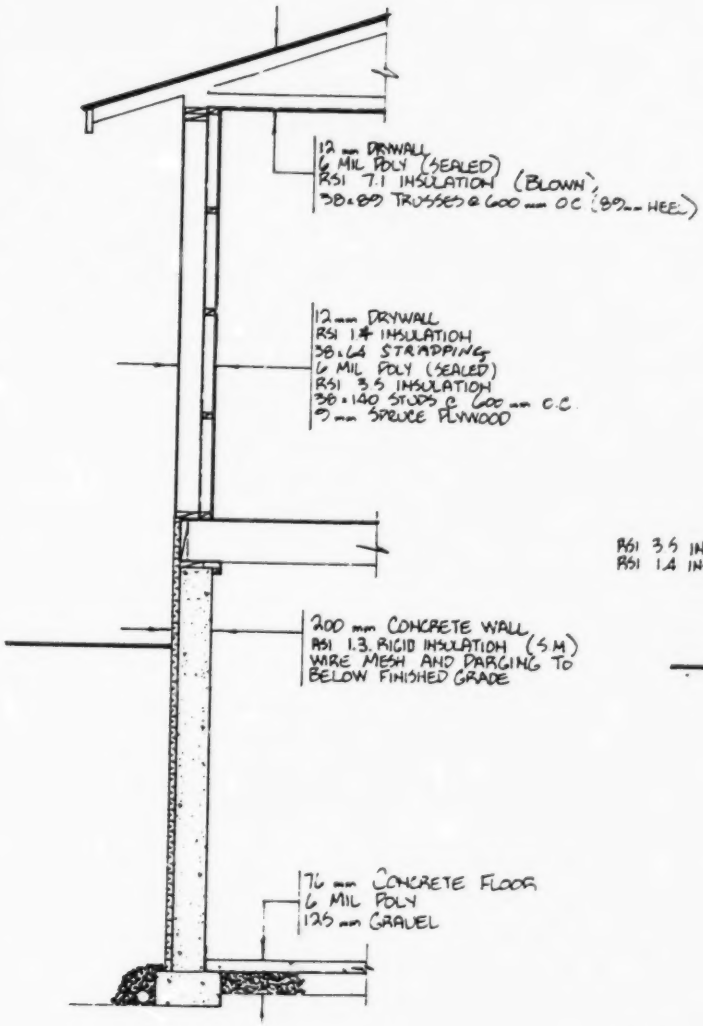

12 mm DRYWALL
6 MIL POLY (SEALED)
RSI 7.1 INSULATION (BLOWN)
38x89 TRUSSES @ 600 mm OC (89 mm HEEL)
12 mm DRYWALL
RSI 1.4 INSULATION
38x64 STRAPPING
6 MIL POLY (SEALED)
RSI 3.5 INSULATION
38x140 STUDS @ 600 mm O.C
9 mm SPRUCE PLYWOOD
200 mm CONCRETE WALL
RSI 1.3 RIGID INSULATION (SM)
WIRE MESH AND PARGING TO
BELOW FINISHED GRADE
76 mm CONCRETE FLOOR
6 MIL POLY
125 mm GRAVEL

Figure 8 Retrofit Ready 1

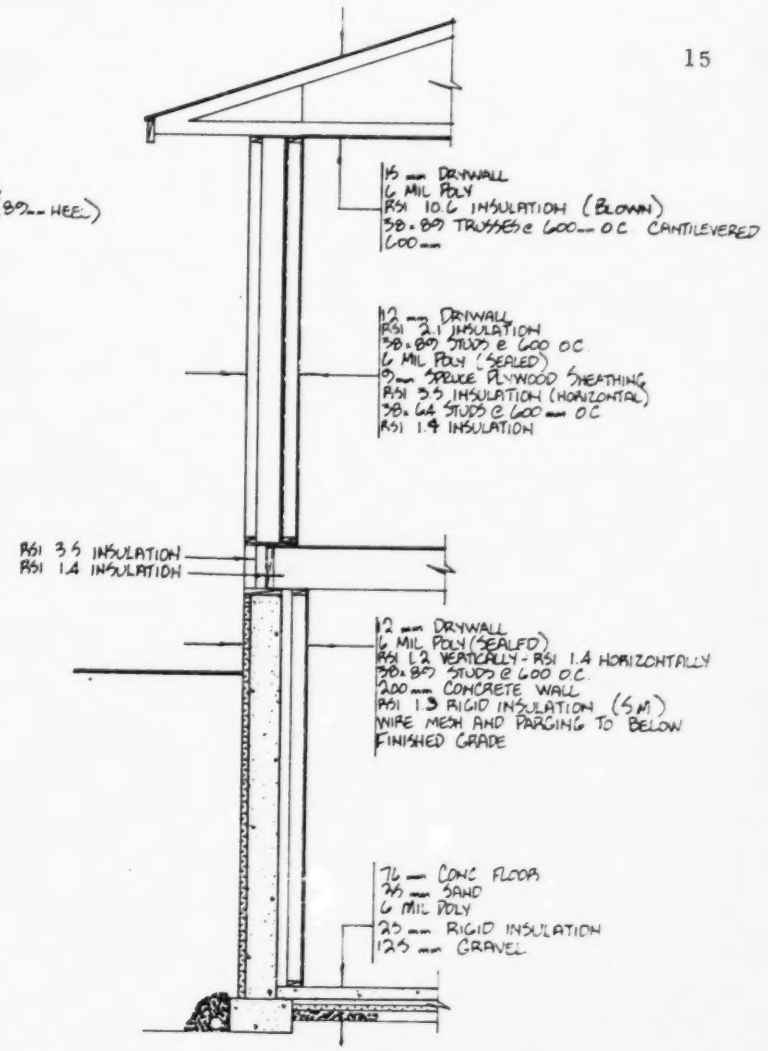

15 mm DRYWALL
6 MIL POLY
RSI 10.6 INSULATION (BLOWN)
38x89 TRUSSES @ 600 mm OC CANTILEVERED
600 mm
12 mm DRYWALL
RSI 2.1 INSULATION
38x89 STUDS @ 600 OC
6 MIL POLY (SEALED)
9 mm SPRUCE PLYWOOD SHEATHING
RSI 3.5 INSULATION (HORIZONTAL)
38x64 STUDS @ 600 mm OC
RSI 1.4 INSULATION
RSI 3.5 INSULATION
RSI 1.4 INSULATION
12 mm DRYWALL
6 MIL POLY (SEALED)
RSI 1.2 VERTICALLY - RSI 1.4 HORIZONTALLY
38x89 STUDS @ 600 OC
200 mm CONCRETE WALL
RSI 1.3 RIGID INSULATION (SM)
WIRE MESH AND PARGING TO BELOW
FINISHED GRADE
76 mm CONC FLOOR
25 mm SAND
6 MIL POLY
25 mm RIGID INSULATION
125 mm GRAVEL

Figure 9 Super Energy Efficient

frame.

- Measures 3, which carries foundation insulation down to the footing.

3. Retrofit Ready, so-called because it concentrates on those aspects which would be difficult to retrofit at a later date. (Figure 8)

- Ceiling insulation RSI 7.1
- Wall insulation RSI 4.9
- Foundation insulation RSI 1.3 full height
- No slab insulation
- Roof trusses with 89 mm heel
- Wall structure is 38 x 140 stud frame @ 600 mm o.c. with vapour barrier, and 38 x 64 horizontal strapping on edge; vapour barrier buried in the wall to protect against damage.
- Foundation insulation 38 mm Styrofoam SM
- Air tight vapour barrier construction with 6-mil polyethylene
- Simple air management system
- Triple glazing on non-solar windows, double glazing on solar windows
- Passive solar design.

Retrofit Ready 2 incorporates additional wall sheathing to bring its thermal resistance to RSI 6.2.

4. Super Energy-Efficient is based on SRC designs intended to reduce space heating consumption to 0.2 GJ/m^2 of heated floor area. (Figure 9)

   - Ceiling insulation RSI 10.6
   - Wall insulation RSI 7.0
   - Foundation wall insulation RSI 3.9
   - Roof trusses with cantilever design
   - 2 layer wall structure of 38 x 89 @ 600 mm o.c. frames
   - 25 mm styrofoam SM slab insulation with 6-mil polyethylene vapour barrier
   - Air tight vapour barrier construction
   - Air management system with heat exchanger
   - Triple glazed windows throughout
   - Thermal doors
   - Passive solar design.

   SEE 2 is similar except that slab insulation is increased to 50 mm SM with a thermal resistance of RSI 1.8.

The study identified housing affordability as a major issue at Tumbler Ridge. With one-income families, qualifying incomes to afford a standard 100 m^2 detached bungalow at 18% mortgage rates are high - beyond the reach of all but mine management staff. (Figure 10). The study suggested

	UNIT COST	DEPOSIT	MORT	MONTHLY P.I. (18%)	ANN. TAX.	MONTHLY P.I.T.	QUALIF. INCOME
100 m^2 DETACHED	76,000 87,000	19,000 21,750	57,000 65,250	836 957	1,500	961 1082	38,400 43,200
80.6 m^2 DETACHED	65,000 74,000	16,250 18,500	48,750 55,500	715 814	1,200	815 914	32,600 36,500
96 m^2 SEMI-DETACHED	65,000 75,000	16,250 18,750	48,750 56,250	715 825	1,440	835 945	33,400 37,800
75 m^2 SEMI-DETACHED	55,000 62,000	13,750 15,500	41,250 46,500	605 682	1,120	698 775	27,900 31,000
54 m^2 ROW	33,000 37,000	8,250 9,250	24,750 27,750	363 407	810	430 474	17,200 18,900
38.4 m^2 APARTMENT	20,000 22,000	5,000 5,500	15,000 16,500	220 242	290	244 266	9,800 10,600
91 m^2 PRE-BUILT	53,000 55,000	13,250 13,750	39,750 41,250	583 605	1,365	697 719	27,900 28,700

* UPPER FIGURES ARE DAWSON CREEK + 0%
* LOWER FIGURES ARE DAWSON CREEK + 20%

Figure 10 Unit Financing Details, 1975 Standard Residential Units at Tumbler Ridge

a reduction in unit sizes to improve affordability (for example, reducing the detached unit from 100 m^2 in floor area to 80.6 m^2, and the semi-detached from 96 m^2 to 75 m^2). In the time since the report was completed, mortgage rates have declined substantially, and the affordability problem has eased.

The second issue raised in the study was the cost of energy conservation measures. If the measures increase the owner's monthly payments (that is, the extra monthly cost of the measures amortized minus the value of their fuel savings) then they jeopardise affordability, and are unlikely to be implemented. As an example, the incremental costs to raise a Standard 100 m^2 detached house to the "Measures" level total $1,512; to raise it to the "Super Energy-Efficient" level totals $11,200. (Figure 11) Monthly fuel bill savings for the same unit range from $31 to $72. (Figure 12). When these figures are translated into monthly terms, the resulting Principle, Interest, Taxes, and Heating (PITH) payments range from $14 less per month for the Measures level of construction to $47 higher for the Super Energy Efficient level (Figure 13) at the 18% interest rates prevailing when the report was written. On this basis, the Measures and possibly Retrofit-Ready levels of construction are cost-effective, but the Super Energy-Efficient level is not. With the higher costs of electric heating, Retrofit-Ready becomes the most cost-effective option. (Figure 14).

	1975 STD.	MEAS #1	MEAS #2	MEAS #3	R.R. #1	R.R. #2	SEE #1	SEE #2
100 m^2 Detached	0	$1,512●	1,528	1,994	4,479	4,939	10,804	11,233●
GJ saved/year	(0)	(68)	(67)	(80)	(111)	(113)	(149)	
80.6 m^2 Detached	0	1,320	1,335	1,753	3,960	4,374	9,634	9,973
GJ saved/year	(0)	(59)	(59)	(70)	(95)	(97)	(127)	
96 m^2 Semi-Det.	0	1,257	1,270	1,609	2,826	4,167	9,371	9,783
GJ saved/year	(0)	(55)	(55)	(55)	(93)	(94)	(125)	
75 m^2 Semi-Det.	0	1,051	1,062	1,362	3,161	3,458	8,160	8,474
GJ saved/year	(0)	(46)	(46)	(46)	(75)	(77)	(100)	
54 m^2 Row Unit	0	589	581	N.A.	2,491	2,619	5,729	5,968
GJ saved/year	(0)	(17)	(17)		(34)	(35)	(47)	
38.4 m^2 Apartment	0	305	310	N.A.	1,197	1,308	3,361	N.A.
GJ saved/year	(0)	(7)	(7)		(15)	(15)	(22)	
Pre-Built Unit	0	1,192		1,525				
GJ saved/year	(0)	(112)		(112)				

Figure 11: Incremental Costs at Tumbler Ridge

	1975 STD.	MEAS #1	MEAS #2	MEAS #3	R-R #1	R-R #2	SEE #1
LARGE DETACHED	0	31 •	31	37	52	53	72 •
SMALL DETACHED	0	28	28	33	46	47	63
LARGE SEMI-DETACHED	0	26			45	45	62
SMALL SEMI-DETACHED	0	22			37	38	51
ROW	0	9			18	19	25
APARTMENT	0	4			9	9	13
PRE-BUILT	0	51					

Figure 12: Monthly Fuel Bill Savings, (Natural Gas at 1982 Rates with 60% Efficient Furnace)

		1975 STD.	MEAS #1	MEAS #2	MEAS #3	R.R. #1	R.R. #2	SEE #1
100 m^2 Detached	18%	-	-14 •	-14	-15	-3	+1	+47 •
	12%	-	-19	-19	-21	-17	-14	+13
80.6 m^2 Detached	18%	-	-13	-13	-14	-2	+1	+43
	12%	-	-18	-18	-19	-15	-12	+13
96 m^2 Semi-Det.	18%	-	-12			-3	+1	+41
	12%	-	-16			-23	-12	+12
75 m^2 Semi-Det.	18%	-	-10			-2	0	+39
	12%	-	-14			-12	-11	+14
54 m^2 Row Unit	18%	-	-3			+9	+10	+38
	12%	-	-4			+2	+2	+20
38.4 m^2 Apartment	18%	-	-1			+4	+5	+24
	12%	-	-2			0	+1	+14
Pre-Built Unit	18%	-	-38					
	12%	-	-42					

Figure 13: Monthly P.I.T.H. Increment Relative to 1975 Standard (For Natural Gas, 1982 Rates, 60% Efficient Furnace)

		1975 STD.	MEAS #1	MEAS #2	MEAS #3	R.R. #1	R.R. #2	SEE #1
100 m^2 Detached	(18%)	-	-38	-37	-42	-40	-37	0
	(12%)	-	-43	-42	-48	-54	-52	-34
80.6 m^2 Detached	(18%)	-	-32	-32	-37	-32	-29	+5
	(12%)	-	-37	-37	-42	-45	-43	-25
96 m^2 Semi-Det.	(18%)	-	-30			-33	-29	+3
	(12%)	-	-34			-53	-42	-26
75 m^2 Semi-Det.	(18%)	-	-25			-25	-24	+10
	(12%)	-	-29			-35	-35	-16
54 m^2 Row Unit	(18%)	-	-7			0	+1	+26
	(12%)	-	-8			-7	-7	+10
38.4 m^2 Apartment	(18%)	-	-2			+1	+2	
	(12%)	-	-3			-3	-2	
Pre-Built Unit	(18%)	-	-77					
	(12%)	-	-81					

Figure 14: Monthly P.I.T.H. Increment Relative to 1975 Standard (Electrical Heating, 1982 Rates)

Implications of Energy-Efficient Housing

- Interest Rates and The Propensity to Invest in Energy Conservation

Mortgage rates have come down dramatically since this study was done. Capital expenditures to reduce energy consumption are more attractive at 12% than at 18%, provided energy prices are still high.

This is shown in Figure 13, where the shifts in interest rates result in a positive shift of as much as $12 to $20 per month (for Retrofit-Ready construction). However, the drop in interest rates does not make Retrofit Ready the preferred energy investment over Measures, except in the case of the large semi-detached unit. Higher energy costs shift the balance towards higher levels of energy conservation (Figure 14). At 18% rates, and with electric heating, Measures construction is still preferred, but at 12%, Retrofit Ready has the greatest returns for most housing types, in the range of $40 to $53/month. However, these savings are still small compared to the effects that interest rates have on mortgage costs. At 18%, a 100 m^2 detached bungalow may cost as much as $957/mpnth, while at 12%, the monthly Principal and Interest has dropped by $270 to $687/month. (Figure 15)

	Amount Mortgaged	Monthly P.I. (18%)	Monthly P.I. (12%)	Monthly Difference	Monthly P.I.T. (12%)	Qualifying Income (12%)
100 m^2 Detached	57,000*	$836	$600	$236	$725	$29,013
	65,250*	957 ●	687 ●	270 ●	812	32,489
80.6 m^2 Detached	48,750	715	513	202	614	24,540
	55,500	814	585	229	685	27,380
96 m^2 Semi-Det.	48,750	715	513	202	634	25,338
	56,250	825	592	233	712	28,500
75 m^2 Semi-Det.	41,250	605	434	171	528	21,111
	46,500	682	490	192	583	23,325
54 m^2 Row Unit	24,750	363	261	102	328	13,127
	27,750	407	292	115	360	14,400
38.4 m^2 Apartment	15,000	220	158	62	182	7,290
	16,500	242	174	68	198	7,918
91 m^2 Pre-Built	39,750	583	419	164	532	21,300
	41,250	605	434	171	548	21,930

* Upper Figures are Dawson Creek + 0%, Lower Figures Dawson Creek + 20%

Figure 15: Sensitivity of Mortgage Costs to Interest Rates (1975 Standard Construction)

- Declining Marginal Utility of Energy Conservation

Another major aspect demonstrated by Study 2, is the declining marginal utility of energy conservation. This is illustrated in Figure 16. For a 100 m^2 detached house, it costs only $22.24/GJ to save the first 68 GJ of energy (from Standard to Measures construction). On an annual basis, this is $2.81/GJ at a 12% interest rate. To save the next 43 GJ (Measures to Ratrofit Ready) costs $69/GJ or $8.72/GJ annually, still an economic investment. But to go from Retrofit Ready to Super Energy-Efficient, a further 38 GJ saving in energy costs $166.45/GJ, clearly uneconomic at the present time. (Any capital investment to save energy which costs less on an annual basis than the cost of energy (about $8.00 to $10.00/GJ at Tumbler Ridge, depending on the fuel) is in theory, cost-effective).

As mortgage rates and energy prices fluctuate, they affect the incentive to invest in the energy conservation measures described in Study 2. (Figure 17).

		MEAS #1	MEAS #2	MEAS #3	R.R. #1	R.R. #2	SEE #1
100 m^2 Detached	Cap. $/GJ	$22.24	$22.80	$24.93	$40.35	$43.71	$72.51
	Ann. (12%)	$2.81	2.88	3.15	5.10	5.52	9.16
	Ann. (18%)	4.05	4.15	4.54	7.35	7.96	13.20
Declining Marginal Utility:		To save the first 68 GJ (STD. to MEAS #1) costs $22.24/GJ To save the next 43 GJ (MEAS #1 to R.R. #1) costs $69.00/GJ To save the next 38 GJ (R.R. #1 to SEE #1) costs $166.45/GJ					
80.6 m^2 Detached	Cap. $/GJ	22.37	22.63	25.04	41.68	45.09	75.88
	Ann. (12%)	2.83			5.27		9.59
	Ann. (18%)	4.07			7.59		13.82
96 m^2 Semi-Det.	Cap. $/GJ	22.85	23.09	29.25	30.39	44.33	74.97
	Ann. (12%)	2.89			3.84	5.60	9.47
	Ann. (18%)	4.16			5.53	8.07	13.65
75 m^2 Semi-Det.	Cap. $/GJ	22.85	23.09	29.61	42.15	44.91	81.60
	Ann. (12%)	2.89			5.33		10.31
	Ann. (18%)	4.16			7.68		14.86
54 m^2 Row Unit	Cap. $/GJ	34.65	34.18		73.26	74.83	121.89
	Ann. (12%)	4.38			9.26		15.41
	Ann. (18%)	6.31			13.34		22.20
38.4 m^2 Aaprtment	Cap. $/GJ	43.57	44.29		79.80	87.20	152.77
	Ann. (12%)	5.51			10.09	11.02	19.31
	Ann. (18%)	7.97			14.53	15.88	27.82
91 m^2 Pre-Built	Cap. $/GJ	10.64 (Excellent)		13.62 (Excellent)			
	Ann. (12%)	1.34		1.72			
	Ann. (18%)	1.94		2.48			

Figure 16: Declining Marginal Utility of Energy Conservation
(Derived from Figure 11: Incremental Costs)

Figure 17

EXTERNAL EFFECTS and the
Incentive to Invest in Energy Measures

Interest Rates	Energy Prices: Low	Energy Prices: High
Low	Little (1977)	Strong (1983)
High	None	Moderate (1981)

- If mortgage rates remain high, and energy costs are still high, there is a moderate incentive to invest in energy conservation, probably, as the study indicates, at the Measures level.

- If mortgage rates come down and energy prices remain high (the present scenario), there will be a strong incentive to invest in energy conservation, at the "Retrofit Ready" or higher levels.

- If mortgage rates are low and energy costs are low, the situation of several years ago, there is little incentive to invest in energy conservation.

- The worst scenario is high mortgage rates and low energy prices, where there is literally no incentive to invest. However, this is an unlikely situation, since interest rates and Canadian energy prices will continue to move in step, with major energy projects being so highly capital intensive.

- Relationship to the Overall Affordability Problem

Aside from these fluctuations, reductions in unit size appear to have the greatest initial effect on reducing monthly mortgage costs, as well as heating bills. One suggestion therefore, is to develop unit designs which include a livable basement, considering that this area is part of the Heated volume of the house (for example, the so-called "bi-level" plan). Other useful devices to improve affordability include reductions in lot costs (suggested in Study 3), and competitive tendering or bulk building procedures which reduce the percentage cost premiums associated with Tumbler Ridge, when compared with a community such as Dawson Creek.

- Institutional Implications

Some of the institutional implications of energy-efficient housing, such as technology transfer and monitoring, are dealt with in this study, while the essential question of how to finance energy-related improvements is discussed in Study 4 (Chapter 2.6).

It appears that in a competitive housing market in existing urban areas,

some speculative builders are willing to offer energy-efficient housing as a marketing strategy. A new resource community is not a conventional market because a great deal of housing is built in a very short period of time at start-up, with very little thereafter. The pace of construction is related directly to growth in primary employment. Builders undertake housing more as contractors to the principal employers in town rather than as developers in their own right. Because both buyers and builders are "captive", the true reactions of the market over a long period of time cannot be predicted. Builders are conservative and innovative measures tend not to be implemented because construction costs are already high, and afforability is a major concern. Incentives by lending institutions could be instrumental in overcoming this resistance, and are discussed in Study 4.

Another important factor, even in a competitive market, is that homeowners may see energy-related measures in terms of a limited time horizon of no more than 8 to 10 years, rather than the expected lifespan of the house or the community. Energy measures exceeding a capital cost of $50 to $70/GJ saved (an 8 to 10 year payback on the $7 to $8/GJ cost of Tumbler Ridge's cheapest energy source, natural gas) are unfavourable. Figure 16 indicates that this would rule out Super Energy-Efficient construction in general, as well as Retrofit Ready for some housing types.

- Applicability of Conclusions to Other Areas

In adapting the results of Study 2 to other resource communities, planners may find that the analysis comes out more strongly in favour of energy conservation (that is, the low interest rate/high energy cost scenario). More remote communities often have energy costs 3 or 4 times those of southern communities, with heating bills approaching mortgage payments. Although Tumbler Ridge is a resource community, it is really part of the southern energy pricing structure, and the results are more indicative of those which could be expected in most urban areas of Canada.

2.5 Study 3: Energy-Efficient Subdivisions

This study develops and assesses the costs and benefits of community design principles for energy conservation, applied to Tumbler Ridge. The study focuses on reducing the capital costs of roads, services, district heating piping, and site development; and on reducing operating costs for residents, businesses, and government, in the form of space heating and transportation costs.

Planning Collaborative Inc. developed design principles in four major areas:

- land efficiency: compact lots and housing clusters
- network efficiency: minimizing the lengths of roads and services
- solar access: orientation and spacing of houses to receive passive solar gain
- wind protection: reduction of wind velocities and infiltration-related heat losses in housing.

This is accomplished with design patterns such as:

- compact lots oriented north-south, along east-west and north-south streets
- housing clusters, primarily in the form of culs-de-sac of 20 to 30 lots (Figure 17)
- retention of major tree shelter belts throughout the community
- compact overall community form
- radial collector roads from the Town Centre to neighbourhoods
- location of the highest density development (apartments) within walking distance of the Town Centre.

These patterns were summarized in refinements to the Community Plan (Figures 18 and 19), concentrating on areas which had not been finalized by the time the study was done. Some of the study recommendations have now been incorporated into the Community Plan.

All of the proposed design patterns have economic benefits. The energy savings of site planning measures to reduce space heating costs vary with the construction quality of the housing unit. The 1982 dollar value of measures for a moderately energy-efficient (Measures) house range from:

- $25 to $45/year for solar access
- $30 to $40/year for wind protection
- $54 to $74/year for the combined effects of solar access and wind prot-

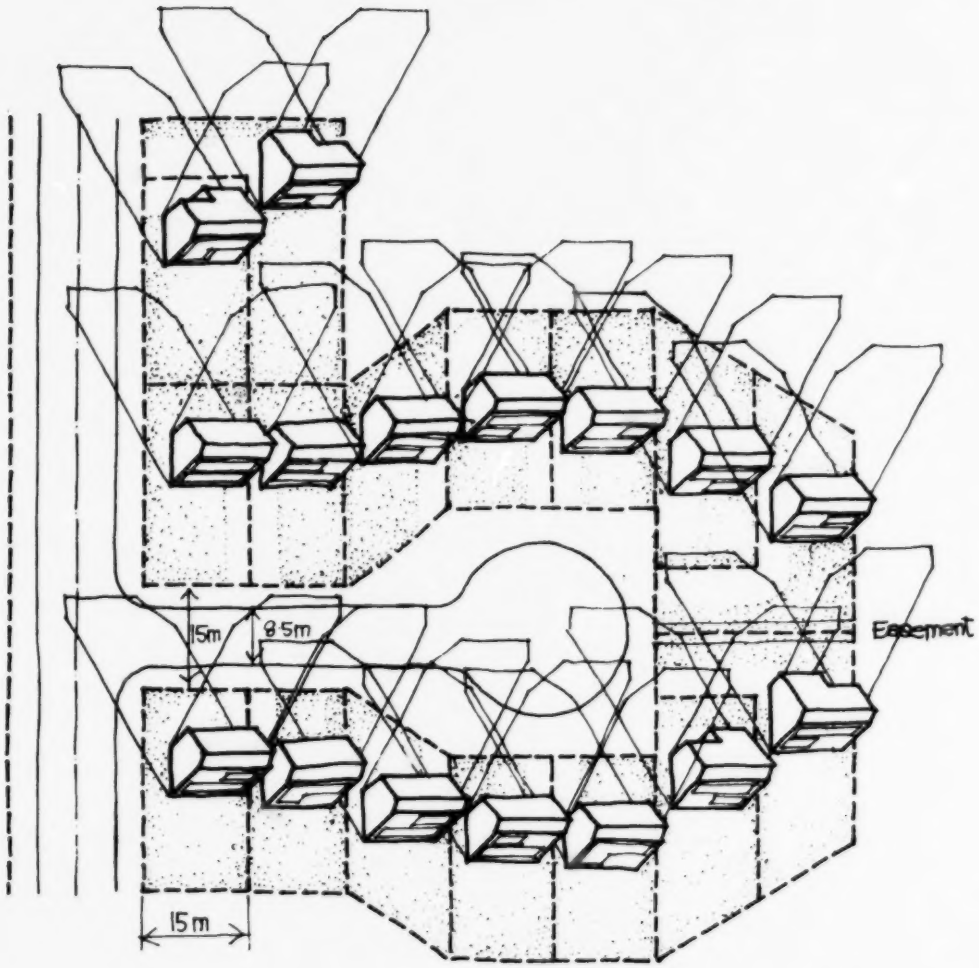


Figure 17

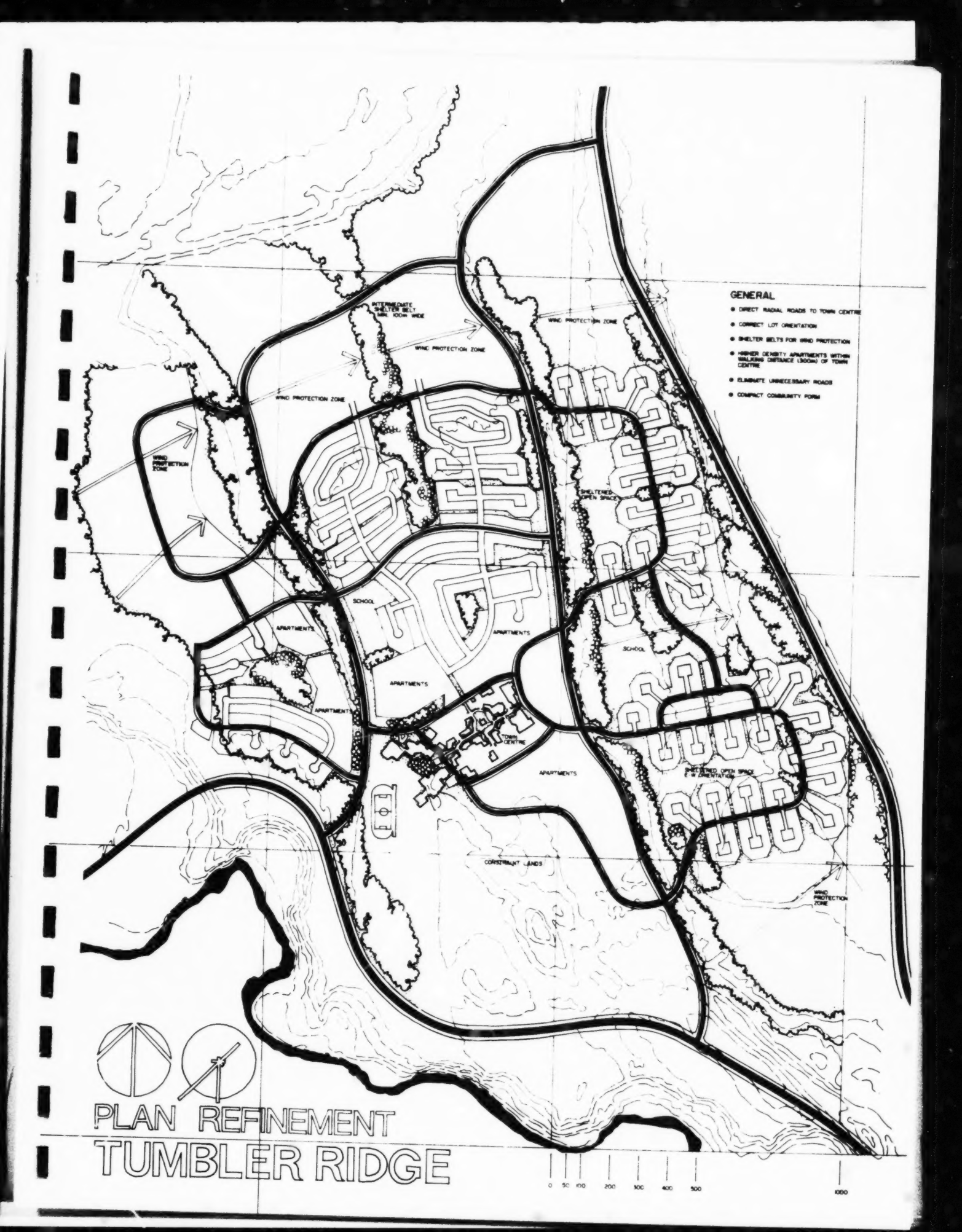
ALTERNATIVE E·W CUL·DE·SAC HOUSING CLUSTERS

TUMBLER RIDGE

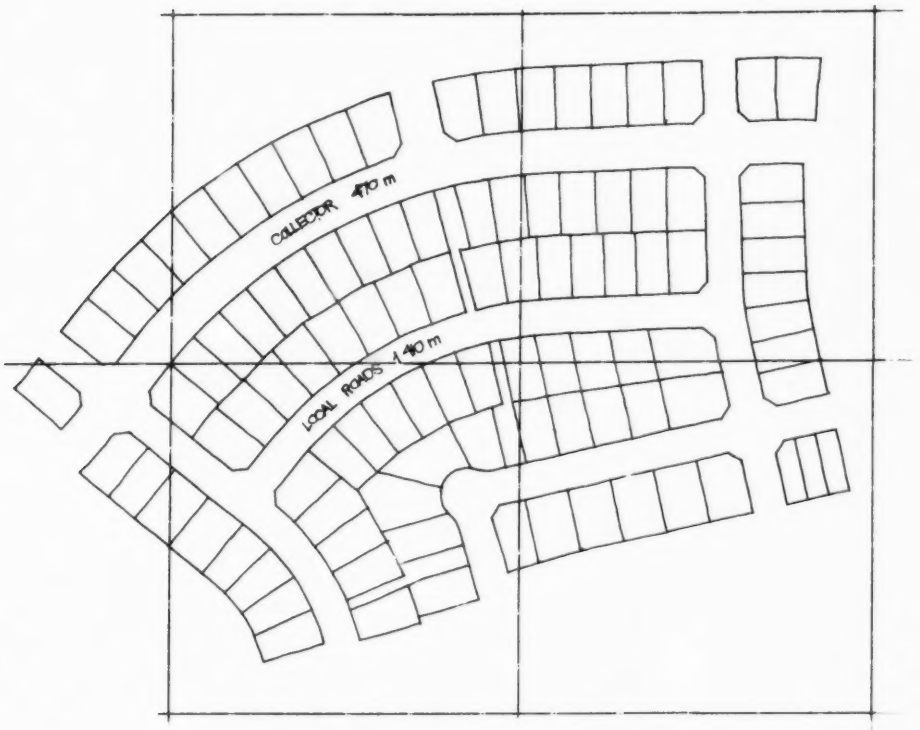
1:1000

Conceptual Plan

Figure 18

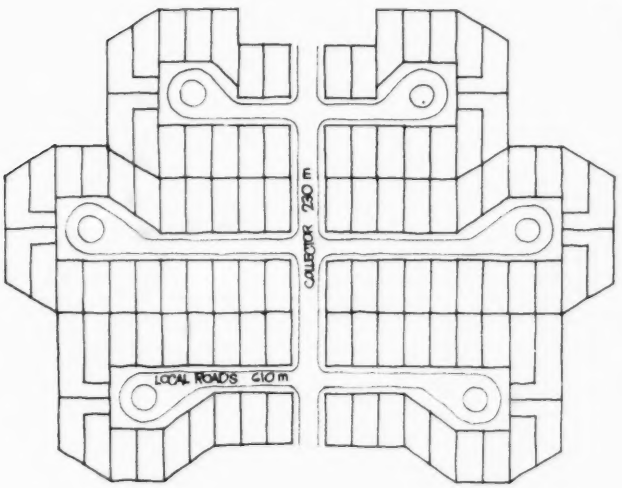


PLAN REFINEMENT
TUMBLER RIDGE



Part of Neighbourhood 1 - 109 lots

Lot size: 18 to 20 m
Local Roads: 1 410 m
Collector: 470 m



Compact Cul-de-Sac Layout - 108 lots

Lot size 15 m
Local Roads: 610 m
Collector: 230 m

Figure 20: Subdivision Comparisons

TUMBLER RIDGE

ection, or 12 to 17% of the annual heat load.

Site planning measures which affect roads and transportation costs are more important, but the dollar values of the savings vary with interest rate assumptions. In comparison with a conventional subdivision, a compact plan can reduce roads and services lengths up to 55% (Figure 20). Part of the reduction comes from narrower lot frontages (18 to 20 m in the conventional plan, 15 m in the compact plan), and part comes from street patterns such as culs-de-sac which serve more lots per given length of roadway than loop or grid patterns. In addition, cul-de-sac roads can be narrower than other local roads because they serve only a small number of lots.

The compact plan results in capital lot cost savings of as much as $8,250 per detached unit and $110/year in operating costs, for annual savings of $1,152 to $1,612/unit (depending on interest rate assumptions). If a district heating system is installed, a further $1,000 to $1,400/detached unit in network capital costs (translated into household heating bill savings of $125 to $175/year when amortized) can also be saved.

At the community plan scale, every km of arterial or collector road which can be removed from the Plan will save nearly $950,000 in capital costs, or $129,000 to $181,000 in interest charges and operating costs annually. These benefits would be reflected in lower lot costs, spread over the entire community.

The study concludes that the highest priority in community design should be given to measures to create compact community and subdivision layouts, and to reduce the lengths of roads and services. Site planning measures to reduce space heating loads have relatively less value, but are still desirable if they can be introduced without significant costs (as appears to be the case).

Implications of Energy-Efficient Subdivisions

Study 3 concludes that the greatest savings result from compact lots and street layouts, and a compact community plan, specfically:

- reduced lot costs
- less fuel use by vehicles
- greater population capacity within a limited townsite area.

Some of these savings are not "energy" costs per se, but do contribute to improving housing affordability, an issue raised in Study 2.

Based as it is, on the principle of accumulating savings of pennies over thousands of households or trips, the Plan is strongly affected by any exceptions to the principles described. For example, a few wider lots not

only increase capital costs for the households directly affected, but also marginally increase the lengths of trips for every vehicle entering the neighbourhood, making the community slightly less compact, and slightly more expensive to serve. The costs of supplying even a few households outside the "compact" area with any "hard" municipal service (such as water supply or sewers) or any "soft" service (such as school bussing, snow plowing, ambulance, etc.) could quickly outstrip the savings accumulated by the compact layout, with development only within its area limits.

While the subdivision layouts were not done strictly with the optimization of a district heating network in mind, the strategies of cul-de-sac design, and reductions in road lengths are likely to be favourable to the development of an economical district heating system.

2.6 Study 4: Alternative Financing Mechanisms

This study by Edwin, Reid & Associates was a follow-up to Study 2: an examination of which levels of added investment in energy conservation were viable, and how to finance the preferred level of investment.

The study examined the interest of various actors in supporting energy conservation features in housing. An example of government support is the Saskatchewan Home Energy Loan Program, which loans out $3,000 for incremental costs repayable over 10 years @ $25/month. It is therefore cost-effective for the homeowner if he can lower his monthly fuel bill by any amount over $25/month. (The provincial average was $33 monthly savings, for a net benefit of $8.00/month).

Financial institutions have been required to change their criteria by CMHC to consider heating in monthly payments (PITH cannot exceed 32% of household income). Thus purchasers of energy-efficient housing need slightly lower qualifying incomes.

Resource companies were unsure of what incentives to offer workers as a result of recent federal budget changes taxing employee benefits. Affordability becomes a major problem, one which was alleviated in the past by low second mortgages provided by the companies. In the future, employees may want additional salary to pay for housing, no matter what its energy efficiency.

Utility companies would not rule out a financing scheme for energy improvements if it was a requirement of approvals from the British Columbia Utilities Commission.

The study concluded that separate financing of an incremental energy investment was unlikely: it could not be secured, and was small relative to interest rate fluctuations. Direct subsidies are possible if governments are willing to provide the necessary funding. A more viable scheme seems to be simply to make the desired levels of energy conservation a mandatory requirement of eligibility for government programs such as B.C. Home, Federal Grants, or CMHC guarantees. This could be supported by analyses showing that the desired levels of conservation have significant economic benefits for the homeowner.

3. Study Relationships

The complexity and diversity of linkages among the Tumbler Ridge energy studies was not realized initially by the clients or consultants. In a comprehensive community energy planning process, these relationships would have to be defined and re-iterated several times in order to arrive at an optimal community energy plan. This kind of process was not possible at Tumbler Ridge because of time and other constraints.

The basic dynamics in the process are between energy supply options and energy conservation options. Since only one study (Number 1) in the Tumbler Ridge series dealt with supply, the primary interations are between Studies 1 and 2; and Studies 1 and 3. Study 4, Alternative Financing Mechanisms, was an adjunct to Study 2 on Energy-Efficient Housing.

Study 1 (District Heating) and Study 3 (Energy-Efficient Subdivisions)

Studies 1 and 3 are complementary. The principal conclusion of Study 3 was that a compact community design reduces capital infrastructure costs and saves on fuel costs for transportation. Secondarily, wind protection and solar access have a minor effect on space heating costs, and therefore, have little impact on energy supply options.

The principal interaction between the two studies is in the use of compact design to reduce infrastructure costs. This is less important for the energy supply options in which the cost of local piping or wiring (for example, natural gas, or electricity) is a small percentage of the delivered cost of energy to the household.

With District Heating, the cost of the local distribution network is 53% of the system's capital cost. Since operating costs (fuel, labour, maintenance, etc.) are relatively low, this system capital cost is the major portion of the total delivered energy cost (66 to 77%, depending on cost estimates and the costs of financing). Study 3 suggested that compact lots and street patterns could reduce roads and services lengths by as much as 55% over a conventional neighbourhood already under construction at Tumbler Ridge. Assuming conservatively that only a 40% reduction in length could be achieved (since some major trunk lines might not be able to be reduced), we would find the following effects on energy prices:

	Conventional Plan		Compact Plan	
Heating Plant	4,430,000		4,430,000	
Distribution Network	6,672,000		4,003,000	
Instrumentation	541,000		541,000	
Engineering	820,000		820,000	
Testing	125,000		125,000	
TOTAL	$12,588,000		$9,919,000	
Amortized @ 12%:	1,590,959	$5.86/GJ	1,253,632	$4.61/GJ
Operating Costs		2.95/GJ		2.95/GJ
Household Delivered Costs		$8.81/GJ		$7.56/GJ
				(14% reduction)
Amortized @ 18%:	2,292,170	$8.44/GJ	1,806,166	$6.65/GJ
Operating Costs		2.95/GJ		2.95/GJ
Household Delivered Costs		$11.39/GJ		$9.60/GJ
				(15% reduction)

Since the benefits of the Study 3 planning principles can be realized with little or no extra financial cost, they are readily implementable. In particular, narrow lots (15 m or less) may be affected by concerns for livability, outdoor amenity, storage and parking, flexibility in laying out housing on the site, and adapting the site to terrain and vegetation conditions, any of which may require wider lots in some instances. Because the principles in Study 3 can be implemented to the fullest extent consisten with other community design objectives and the conditions mentioned above, there is, in effect, no tradeoff between Studies 1 and 3.

Study 1 (District Heating) and Study 2 (Energy-Efficient Housing)

The interactions between energy supply options (1) and energy-efficient housing (2) are complex. As policy options, they may be mutually exclusive (that is, the community will have one or the other, but not both. For example, if a cheap energy supply is available, energy conservation levels in housing will be moderate, probably at the Measures level. If fuel costs are high (as with electricity), there will be greater pressure to invest more heavily in energy conservation, as described in Study 2. The pricing and availability of competing energy sources is a critical factor in determining directions for community energy policy.

The interactions also work in reverse. Energy conservation levels determine the size of the market, or total community energy demand. The smaller this market, the more expensive it is to serve. This is especially true with District Heating.

Figure 21 shows how the total Community Heating Demand declines from 350,600 GJ per year, with Standard levels of construction to 158,400 GJ with Super Energy-Efficient construction, a 55% reduction in energy use.

Residential		Standard		Measures		Retrofit		S.E.E.	
Unit Type	No. Units	Unit GJ	Total 000 GJ	Unit GJ	Total 000 GJ	Unit GJ	Total 000 GJ	Unit GJ	Total 000 GJ
Large Det.	507	171	86.7	103	52.2	60	30.4	22	11.2
Small Det.	510	144	73.4	85	43.4	49	25.0	17	8.7
Large Semi	65	146	9.5	91	5.9	53	3.4	21	1.3
Small Semi	70	110	7.7	64	4.5	35	2.5	10	0.7
Row	110	53	5.8	36	4.0	19	2.1	6	0.7
Apartment	740	24	17.8	17	12.6	9	6.7	2	1.5
Pre-Built	388	225	87.3	113	43.8	113	43.8	113	43.8
	2,390		228.2		166.4		113.9		67.9
Domestic Hot Water			53.3		53.3		53.3		53.3
Residential Sub-Total			281.5		219.7		167.2		121.2
Commercial									
Space Heating			64.1		47.0		32.2		32.2
Domestic Hot Water			5.0		5.0		5.0		5.0
Commercial Sub-Total			69.1		52.0		37.2		37.2
COMMUNITY TOTAL			350.6		271.7		204.4		158.4
					55% Reduction				
District Heating Thermal Losses (9%)			31.6		24.5		18.4		14.3
District Heating Total			382.2		296.2		222.8		172.7

Figure 21: COMMUNITY HEATING DEMAND

The effect on District Heating is to raise the unit energy cost from $7.56/GJ with Standard construction to $12.40/GJ with Super Energy-Efficient construction (Figure 22). When the community's total annual space heating cost is computed for all homes and other buildings, the increasing unit energy cost of District Heating dampens the 55% reduction in energy use to only a 25% reduction in energy costs, from $3,425 million (Standard construction) to $2.563 million (Super Energy-Efficient Construction).

Capital (000 $)	Standard	Measures	Retrofit	S.E.E.
Heating Plant*	5,716	4,430	3,332	2,583
Distribution	6,672	6,672	6,672	6,672
Instrumentation	541	541	541	541
Engineering	820	820	820	820
Testing	125	125	125	125
TOTAL	13,874	12,588	11,490	10,741
Annualized Costs (12%, 25 years)	1,753	1,591	1,452	1,358
$/GJ	$5.00	$5.86	$7.10	$8.57

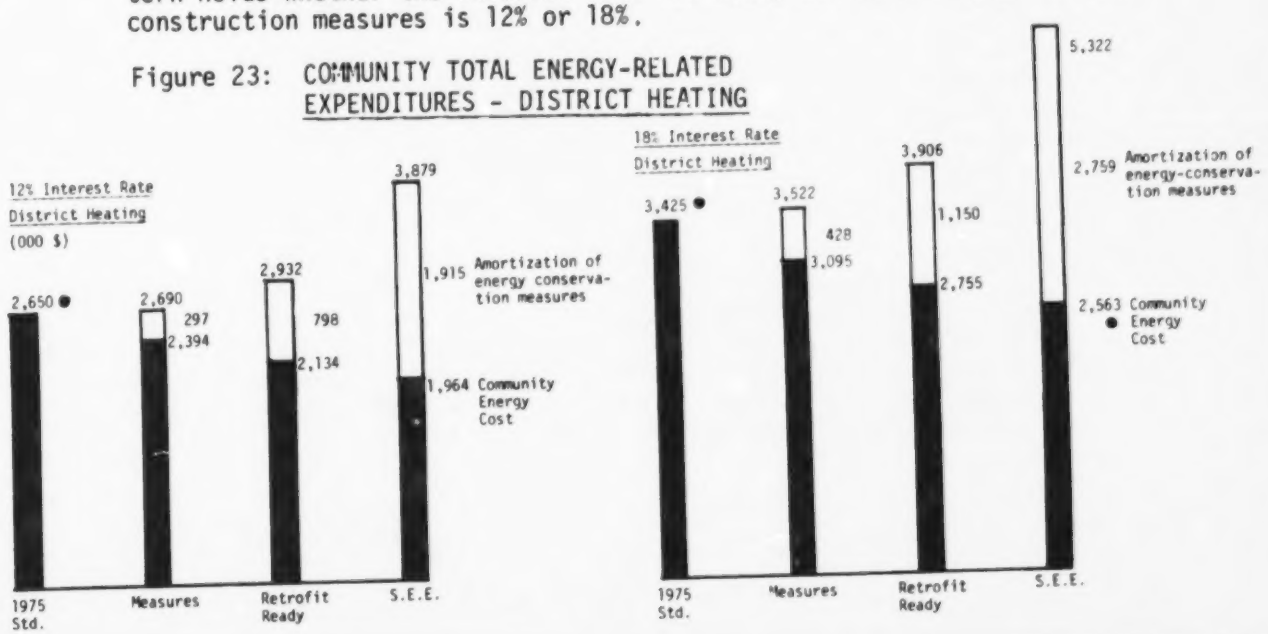
* Heating Plant size assumed to be directly proportional to Community Heating Demand (see Figure 21).

Operating (000 $)				
Labour	300	300	300	300
Coal	328	253	190	147
Electricity	107	107	62	62
Materials	76	76	59	59
Transportation	86	66	50	39
TOTAL	897	802	661	607
$/GJ	$2.56	$2.95	$3.24	$3.83
TOTAL CAPITAL + OPERATING $/GJ	$7.56 ●	$8.81	$10.34	$12.40 ●

Figure 22: DISTRICT HEATING CAPITAL AND OPERATING COSTS

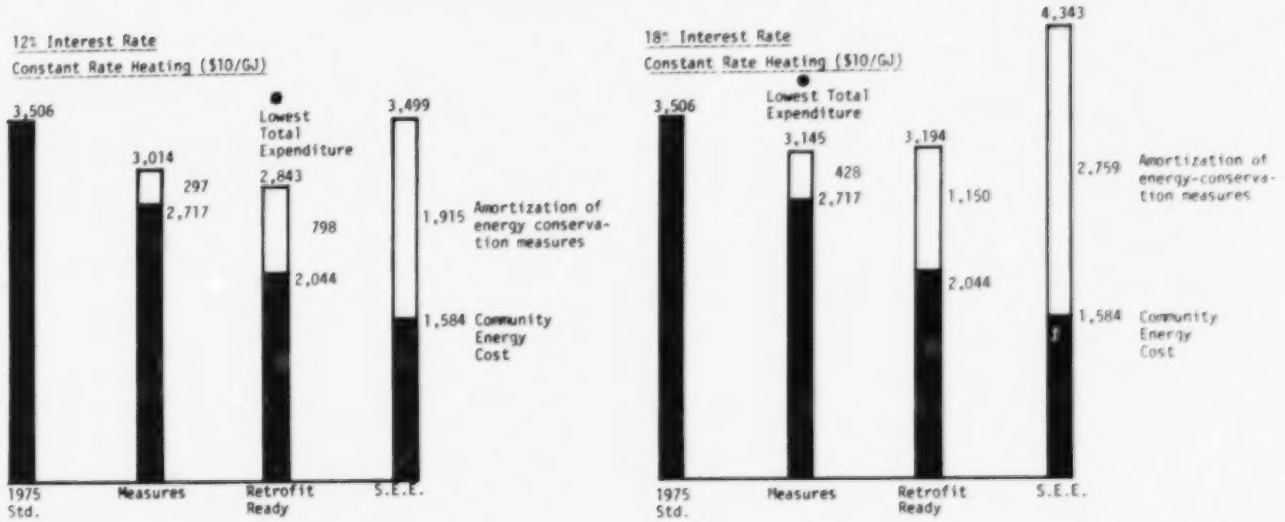
To the community energy planner looking at a total expenditure of energy costs and energy saving measures, an interesting picture emerges. When the community energy cost is added to the amortized cost of construction measures for all buildings in the community, for District Heating, the lowest total expenditure is achieved with the lowest level of construction: Standard or possibly, Measures (which has a total expenditure close to Standard). (Figure 23) This results because of the rapid rise in unit energy costs as aggregate energy use is reduced. The same pattern holds whether the interest rate for money borrowed to pay for the construction measures is 12% or 18%.

Figure 23: COMMUNITY TOTAL ENERGY-RELATED EXPENDITURES - DISTRICT HEATING



On the other hand, if fuel with a relatively constant unit cost is assumed (such as natural gas or electricity), the lowest aggregate expenditure level is achieved with Retrofit Ready (@ 12% borrowing rate) or Measures (@ 18%). (Figure 24) This reflects the earlier comment that lower interest rates encourage higher investments in energy conservation. It may be that competing external energy sources, although less sensitive to the size of the market than a local system, may still show some increases in unit costs as the size of the market decreases. This would result in much closer differences between the different categories of construction.

Figure 24: COMMUNITY TOTAL ENERGY-RELATED EXPENDITURES - CONSTANT RATE SOURCE



There are several implications to this analysis. District Heating appears to need a minimum size of market in order to compete with other external energy sources. The community of Tumbler Ridge probably represents an appropriate scale for the introduction of District Heating. DH also serves most effectively a high density compact community of relatively inefficient buildings, therefore, it would be most cost-effective for an area such as the Town Centre. Other constant rate energy sources are more suited to less dense, more spread-out neighbourhoods of energy-efficient buildings.

Study 2 (Energy-Efficient Housing) and Study 3 (Energy-Efficient Subdivisions)

Interactions between energy-efficient housing and subdivisions are described within Study 3. Wind protection and solar access are environmental responses whose value will vary with the location of the community. Wind is an important factor at Tumbler Ridge, while solar access is less so, because of the Town's high latitude, which gives low winter sun angles when passive solar gain would be most useful.

The effects of increasingly energy-efficient construction are to isolate the building from its environment, therefore, there is less benefit from such environmental responses. Interestingly, while the absolute amount of energy saved goes down, as well as its dollar value, the percentage contribution of these measures in reducing heat load, increases. (Figure 25)

The roads and services reductions proposed in Study 3 have a direct effect on housing affordability, discussed as an issue in Study 2. The maximum effect is most noticeable at higher interest rates ($134/month @ 18%) than at lower rates ($96/month @ 12%). Even at the lower interest rate, the savings from compact lot costs alone are at least double those available from improving the energy-efficiency of construction (which are, at the most, $50/month).

With measures such as narrower lots, there may be a tradeoff between these cost savings and a reduced perceived sense of livability which some people may experience, even if 15 m lots can accommodate virtually the same activities as 18 or 20 m lots.

Figure 25

Combined Effects of Wind Shelter and Solar Access

Annual Energy Savings in GJ

	Standard	Measures	Retrofit	E - E
Solar Orientation "Conservative"	8,734.5 GJ	7,997.5	7,053.1	4,831.0
50% of Wind Shelter	9,687.5	9,425	3,382.5	2,701.0
Total GJ	18,422.2	17,422.5	10,435.6	7,532
1982 $ Value				
NG, 65% Furnace @ $7.50/GJ	$138,166.50 $57.71/du	$130,668.75 $54.58/du	$78,267.00 $32.69/du	$56,490.00 $23.60/du
Electrical @ $10.21/GJ	$188,090.66 $78.57/du	$177,883.72 $74.30/du	$106,547.47 $44.51/du	$76,901.72 $32.12/du
Percentage of Total Heat Load	8.9%	12.7%	9.3%	12.1%
Solar Orientation "Optimistic"	15,722 GJ	14,395.5	12,696	8,696
50% of Wind Shelter	9,687.5	9,425	3,382.5	2,700.9
Total GJ	25,409.7	23,820.5	16,078.5	11,396.9
1982 $ Value				
NG, 65% Furnace @ $7.50/GJ	$190,572.75 $79.60/du	$178,653.75 $74.62/du	$120,588.75 $50.37/du	$85,476.75 $35.70/du
Electrical @ $10.21/du	$259,433.00 $108.37/du	$243,207.30 $101.59/du	$164,161.48 $68.57/du	$116,362.30 $48.61/du
Percentage of Total Heat Load	12.3%	17.3%	14.3%	18.3%

4. Conceptual Framework

The basic policy issue faced by community energy planners is to match the energy supply options available to a community with an appropriate level of investment in energy conservation measures. For a community with only one or two supply options, the issue resolves to a relatively straightforward selection of an energy conservation level for building construction. In a community such as Tumbler Ridge, complicated by 5, 6, or as many as 10 supply options, the analysis becomes a more complex "competition" among sets of supply/conservation combinations. Some of these combinations will be more sensitive than others to fluctuations in external factors such as inflation and interest rates; leaving the planner(s) to select the combination which performs best under the expected ranges of posiible "states of the world".

In general, planning can be described as a sequence of tasks, such as the following:

- setting goals and objectives
- developing alternative solutions to meet these objectives
- predicting their consequences under a range of external conditions
- evaluating these consequences
- selecting a preferred alternative for implementation.

The experience of the Tumbler Ridge energy studies provides a basis for adapting this generalized process to a conceptual framework for community energy planning. This framework is based primarily on the interactions between an energy supply analysis (exemplified in Study 1) and building energy conservation options (Study 2), as discussed in the preceding chapter.

These planning tasks are elaborated to suit the circumstances of a particular community application (for example, Figure 26). The degree of elaboration depends primarily on the number of energy supply options available to the community. Both the supply and conservation aspects of the process may have to be analysed in some detail, in order to be certain of defining the full range of solutions. In Study 1, six energy supply options were investigated in an initial report, two of which were carried on to more detailed preliminary design in subsequent cycles of the process. It appears important, even in early cycles of the process, to prepare cost and energy estimates accurately, so that initial options are not included or excluded on the basis of figures later to proven to be incorrect.

Figure 26 describes energy planning as an iterative process, which may be recycled in whole or in part, several times. The number of times this is done will depend on external factors such as interest rates, inflation, and energy prices, which are varied in the sensitivity analysis to deter-

mine how the various alternatives will perform under different assumptions. Generally, in order to simplify the process, the sensitivity analysis will postulate a limited number of scenarios: a "trends" projection of current conditions, together with high and low estimates of the various factors.

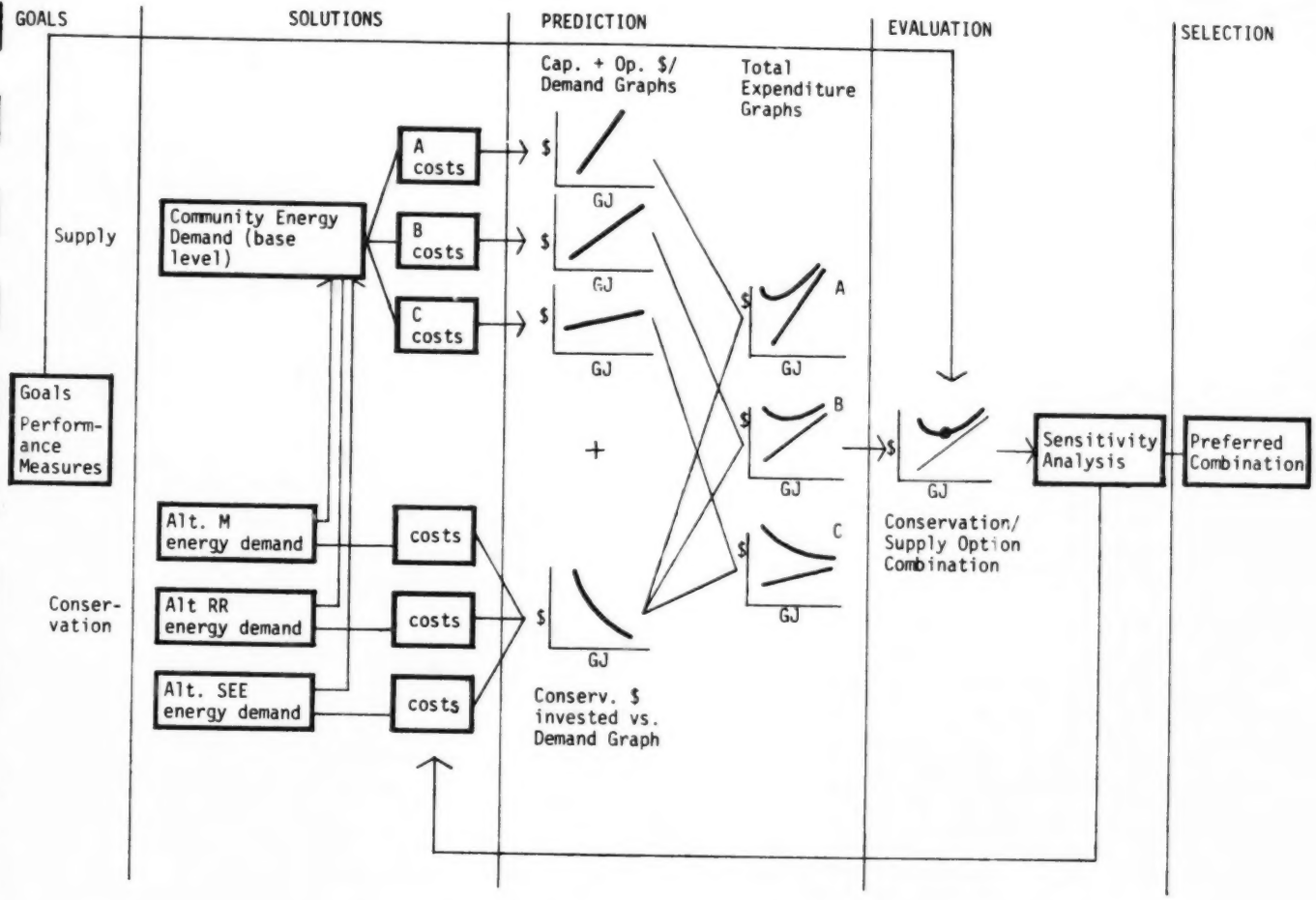
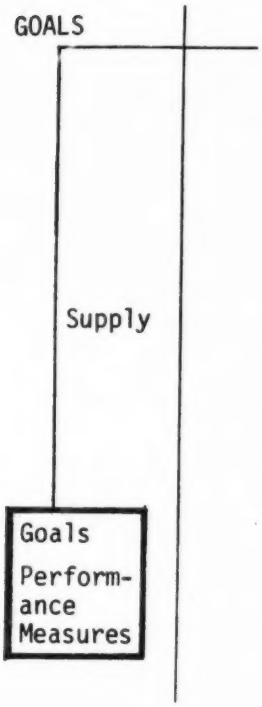


Figure 26: COMMUNITY ENERGY PLANNING PROCESS

Figure 26 can be regarded as an example of a community energy planning process which could have been followed at Tumbler Ridge, involving these steps:

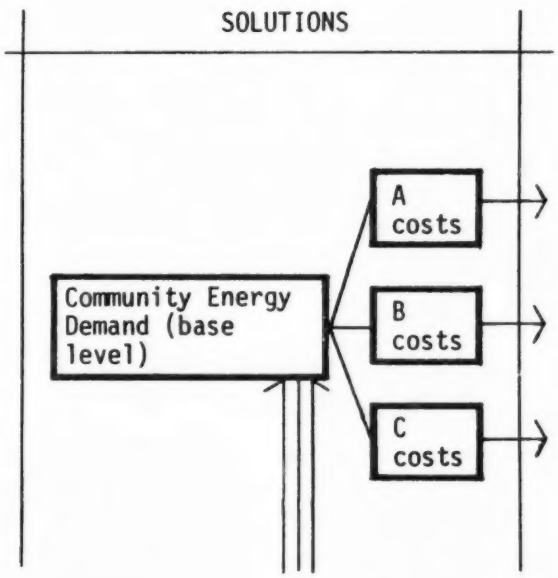


1. Goals and Objectives

- Define primary goals, such as the minimization of community energy-related expenditures. (As illustrated in Figure 23 and 24, these are made up of the money spent on energy for space heating + the costs of energy conservation measures)
- Define secondary objectives such as an assured energy supply, peaking and safety factors. (These define conditions for the consideration of certain supply options and supply parameters for later detailed design)

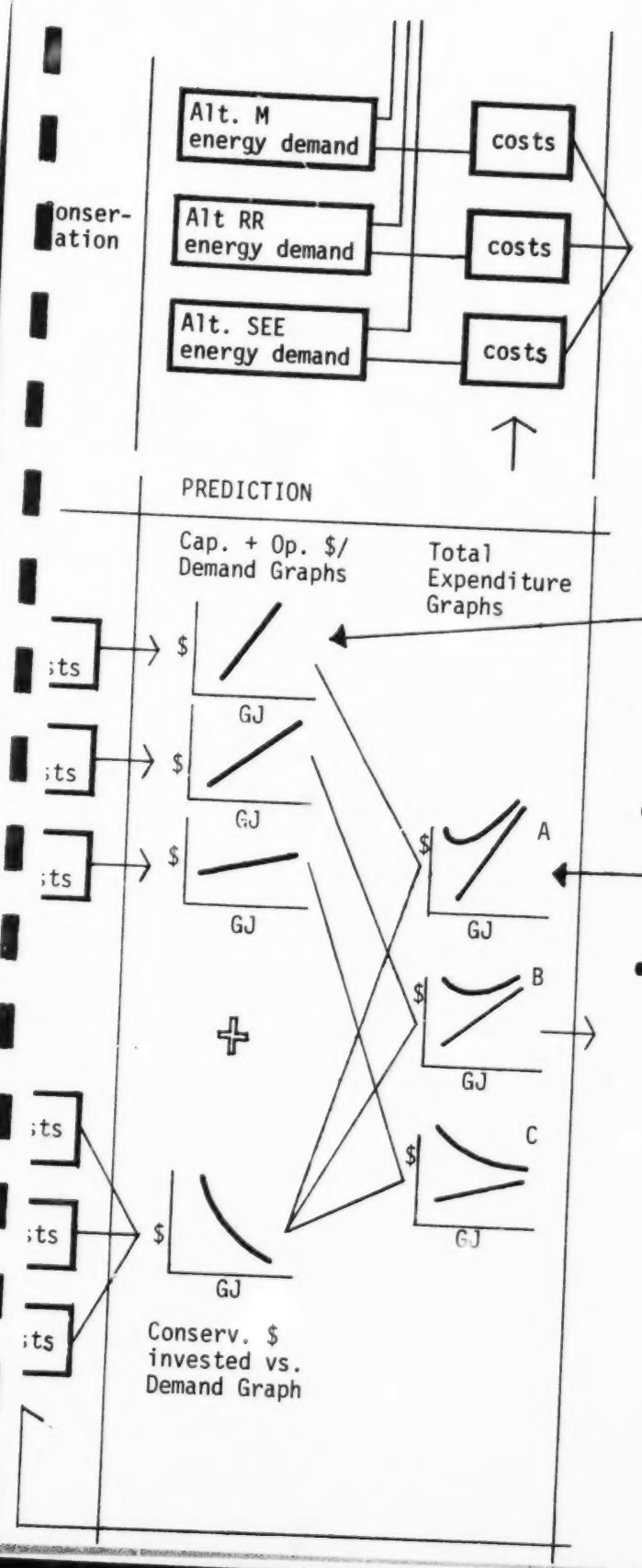
2. Alternative Solutions

These would be developed for both supply and conservation aspects of the process.



Energy Supply

- Identify energy supply options (denoted "A", "B", "C", in the diagram)
- Calculate the highest community heating energy demand, consistent with a base level of construction, such as "Standard". (For example, Figure 3)
- Calculate the capital and operating costs for each supply option. (This is done for local, rather than external supply options) (Figure 22)
- Recycle the calculation for other energy demand levels (input from different conservation levels of construction) (Figure 22)

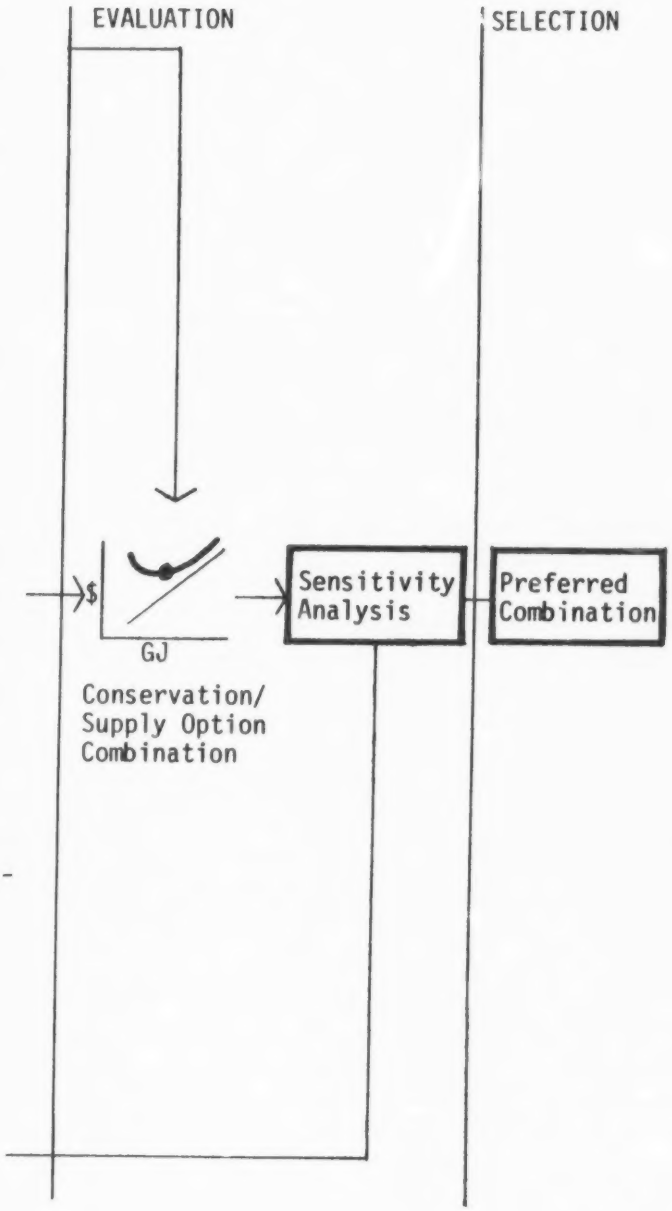


Energy Conservation

- Identify a base level of construction, and a limited number of energy-efficiency levels ("M", "RR", and "SEE" in the diagram)
- Calculate the incremental construction costs for each level (vs. the base level of construction) for each major building type, and total these costs for all buildings in the community.
- Calculate the incremental energy savings for each level (compared with the base level of construction) for each building type (Figure 11) and again total for all buildings in the community.

3. Prediction

- Graph the cost curves for each energy supply option (i.e. the rate at which prices rise in relation to the amount of energy sold) (Figure 22)
- Graph the total community energy demand (GJ) vs. the total extra (incremental) expenditure for each level of construction. ($)
- Combine the energy conservation graph (lower) with the cost curve graph for each supply option (upper) to yield total energy-related expenditure graphs for each supply option (examples: Figures 23 and 24).
- Calculate the lowest aggregate expenditure in each case; i.e., the level of conservation which is appropriate for each supply option. (noted by • in Figures 23 and 24)



4. Evaluation

- Compare the various supply/conservation combinations
- Recycle the entire process in a sensitivity analysis, varying factors such as
  - energy price levels
  - inflation
  - interest rates
- Select the alternative with the consistently lowest community energy cost under the sensitivity analysis.

4.1 Conclusions

The selection of an energy supply/conservation combination can be made by default. At Tumbler Ridge, a conceptual framework for a comprehensive energy planning process was not available, and appropriate institutional or financial mechanisms were not found to deal with some of the individual study conclusions, such as investment in, and management of, a centralized DH system; or investment in the incremental costs of energy-efficient house construction. This limited implementation of the findings of the Tumbler Ridge energy studies.

- Energy Planning in Perspective

On the supply side, community energy planning is strongly conditioned by external factors, notably the availability of fuels and their delivered costs to the community. These are relatively predictable on a year by year basis. Both supply and conservation projects are affected by interest rates which influence the propensity to invest in any capital project. These are less predictable, with fluctuations on a monthly basis. Long range energy planning is difficult, and alternatives must be selected which will perform well under a range of assumptions about the future.

While housing afforability was shown to be a major concern in resource communities, energy conservation appears to have a minor role relative to factors such as construction costs and mortgage payments. In terms of those factors which may be under the control of the community development team, affordability can be greatly improved by reducing the size and costs of housing, and by reducing lot costs (assuming that these savings can be passed on to consumers). Another factor which can greatly improve the affordability of housing in general and energy conservation measures in particular, is interest rate subsidies, but these policy tools are usually available only to senior levels of government.

- Development Process

One of the most important outcomes of the Tumbler Ridge energy studies was the explicit recognition of the role of energy planning in the community development process. In view of the multi-dimensional nature of this process, tradeoffs which result in less than ideal energy systems and costs will often have to be made. Energy planning enables decision makers to value what is being lost and gained under such conditions.

The community development process is complex, and over the course of time, acquires a momentum which can be difficult to control. Thus, to be successful, energy planning must be introduced at an appropriate time in the process, within the parameters and constrtaints of the development program. For example, the planning of innovative energy supply options such as Dis-

trict Heating must be started well in advance of other activities, so that the system can be in place for use in houses as they are constructed. Consistent and accurate information on the costs and benefits of supply and conservation options must be available when required in the planning process. Implementation must consider other aspects such as the borrowing capacity of the community development corporation, and compulsory participation by consumers.

- Implementation

Implementation issues should be dealt with at the start of financial planning for development. For example, legislation and the organizational structure for a community to manage a DH system should be considered by the appropriate authorities, preferably before such a system becomes one of the energy supply options investigated. Community designers must be assured that regulatory agencies and lending institutions will react favourably to improved construction quality, with its higher capital, but lower operating costs. Market research may have to be undertaken to assess consumer reactions to reduced lot sizes, cul-de-sac clusters, bi-level house designs, attached housing types, etc. which may be contemplated in energy-efficient community design. All of these aspects are necessary complements to a community energy planning framework.

- Research Directions

The Tumbler Ridge energy studies listed in the Bibliography following provide more detailed information on the aspects of community energy planning discussed in general in this report. While Tumbler Ridge represents a unique case study of applied energy planning, other general research is available on aspects similar to those addressed at Tumbler Ridge; such as energy supply, housing, and community design.

CMHC has funded research on various aspects of community design and energy conservation, such as local transit systems, solar access, land-efficient housing, and so on. The Ontario Ministry of Energy has just completed a set of handbooks on energy conservation for municipal planners, and the Ontario Ministry of Municipal Affairs and Housing has completed a series on site design and energy conservation. The Governments of Saskatchewan and Alberta have pioneered housing demonstration projects for prairie conditions, resulting the construction of hundreds of units of energy-efficient housing, in centres such as Saskatoon and Regina. District heating demonstration projects have been completed at LeBreton Flats in Ottawa and Kapuskasing, and systems have been in place in many downtown areas for a number of years. The Ontario Ministry of Energy has also published monographs on DH experience in Europe.

The Tumbler Ridge studies also point the way to future research in community energy planning. Many of the technical aspects of energy-efficient housing and community design are well advanced, but much work needs to be

5. Bibliography

(Organized by Date of Publication)

R.A. Rabnett et al; Tumbler Ridge Conceptual Plan Update, (March, 1981)

CoGeneration Associates Limited; Analysis of Integrated Energy Systems and Feasibility of District Heating for Tumbler Ridge, (October, 1981)

INTEG; Tumbler Ridge District Heating Feasibility Report, (April, 1982); supplementary report (May, 1982)

D.W. Thomson Consultants Ltd.; Analysis of the Heating System Options and the Installed Costs at Builder Level for the Domestic Hot Water and Space Heating Systems Within the Proposed Buildings at Tumbler Ridge, (April, 1982)

DHM Energy Consultants; Review of Reports Prepared for the Proposed District Heating System at Tumbler Ridge, (June, 1982)

Saskatchewan Research Council; Tumbler Ridge Cost-Effective Energy-Efficient New Housing, (Canada Mortgage and Housing Corporation, August, 1983)

CoGeneration Associates Limited; Tumbler Ridge District Heating Study: Summary of Findings, (Canada Mortgage and Housing Corporation, August, 1983)

Planning Collaborative Inc.; Tumbler Ridge Energy-Efficient Subdivision and Community Designs, (Canada Mortgage and Housing Corporation, August, 1983)

Edwin, Reid & Associates; Tumbler Ridge Alternative Financing Mechanisms for Energy-Efficient Housing, (Canada Mortgage and Housing Corporation, August, 1983)

done in modifying and refining the engineering design of DH systems for Canadian conditions. Other communities may offer the potential for using the excess heat generated by industrial processes, or for using untapped fuels such as peat or biomass. Work is also necessary in the institutional and implementation aspects of DH and energy-efficient housing, to deal with some of the issues raised at Tumbler Ridge. Market research on consumer aspects of energy conservation has also been mentioned. Above all, other Tumbler Ridges must be found, where energy planning can be integrated into the community development process, and the lessons of Tumbler Ridge applied and adapted to new circumstances. Hopefully the conceptual framework proposed in this report provides a basis for making informed community energy decisions for the Tumbler Ridges of the future.

POOR

QUALITY

ORIGINAL